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STRATEGIC TECHNOLOGIES FOR THE ARMY OF THE TWENTY-FIRST CENTURY

HEALTH AND MEDICAL SYSTEMS

**Board on Army Science and Technology
Commission on Engineering and Technical Systems
National Research Council**

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Preface

The Assistant Secretary of the Army for Research, Development and Acquisition [ASA(RDA)] wrote to the Chairman of the Board on Army Science and Technology in March 1988 to request a study under the auspices of the National Research Council. The study's goal would be to assist the Army in improving its ability to incorporate advanced technologies into its weapons, equipment, and doctrine. The time period to be addressed by the study was specified to extend at least 30 years into the future. The three study objectives stated in the request were to (1) identify the advanced technologies most likely to be important to ground warfare in the next century, (2) suggest strategies for developing the full potential of these technologies, and (3) project implications for force structure and strategy of the technology changes.

The ASA(RDA) expressed the belief that the expert, independent advice provided by such a study would help the Army in selecting those strategic technologies that offer the greatest opportunity for increasing the effectiveness of forces in the field. The study would also assist the Army in designing current research and development strategies to ensure that such advanced technologies do become available for future Army applications.

To conduct the study, the National Research Council organized nine science and technology groups and eight systems panels within the Committee on Strategic Technologies for the Army (STAR). These were subordinated to a Science and Technology Subcommittee and an Integration Subcommittee, respectively. In addition, a Technology Management and Development Planning Subcommittee was set up. These three subcommittees reported directly to the study chairman. An Executive Committee aided the study chairman with policy guidance and served as the principal channel for communication with senior Army leadership.

The majority of the research and drafting work on the auxiliary reports was performed under the project structure described above. The Integration Subcommittee and its eight systems panels were responsible for preparing reports, which are being produced as stand-alone reports. Each of these system panel reports translates projected technological opportunities into systems capabilities that are likely to be important to the Army in the next 20 to 30 years, given the military context projected by the Technology Management and Development Planning Subcommittee. This report of the Health and Medical Systems Panel (see Appendix B for brief biographies of panel members) examines and makes recommendations regarding concepts that could have a significant impact on Army health and medical systems by 2020. These concepts are derived from the application of new and emerging

technologies and fall into the areas of prevention and treatment of disease and injury during peacetime and war.

Each of the panels retained responsibility for its own report. And while considerable effort was made to harmonize the documents, differences in substance and tone remain.

The study has produced a number of other reports, beyond the Health and Medical Systems report presented here. All are being published under the series title, *STAR 21: Strategic Technologies for the Army of the Twenty-First Century*. The reports of the nine technology groups, under the Science and Technology Subcommittee, have been joined together and produced as one volume of technology forecast assessments. The report of the Technology Management and Development Planning Subcommittee is being produced as a stand-alone report in the same manner as the systems panel reports. A main report, which conjoins and extends the findings of all the subsidiary parts of the study committee, is already in print.

During the study, the ASA(RDA) offered the Army's cooperation to supply the technology users' perspective, provided such involvement did not compromise the independence of the National Research Council's study and review processes. High-level civilians and military officers from the Department of the Army were assigned to support the study committee. The chief scientist of the Army Materiel Command ensured that each STAR study group received support and involvement from Army personnel as desired. This was accomplished by appointing a group of senior Army liaison personnel, drawn largely from Army laboratories and procurement commands. The individual Army liaison personnel assisted the various study panels in gaining access to Army programs and activities as needed.

In addition to the frequent contact provided by the Army liaison personnel, an Army Mission Advisory Group was formed of senior Army and other service personnel, to provide a source of information about projected threats and the future environment. This group, which convened about halfway through the study, provided another means for the STAR participants to interact with Army representatives regarding the progress and appropriate focus of the study.

During the course of the study, over a hundred meetings and workshops, lasting one or two days each, were held by the various subcommittees, panels, and groups, so that members could interact with one another as well as receive briefings from the Army and other organizations as needed. In addition, three major coordination meetings were held, during which representatives of the various subcommittees, panels, and groups presented summaries of their activities for the benefit of other study participants, in an effort to identify significant gaps in coverage.

The National Academy of Sciences, the National Research Council, and the STAR Study Committee wish to acknowledge their indebtedness to the U.S. Army for its continuous and generous support and encouragement

throughout the STAR study. The attention and encouragement of the top managers for Army research and development were of immense benefit. Likewise, the interest of the Army liaison personnel and the help they provided were major factors in making the study possible.

The participants also wish to express their gratitude to the STAR study staff at the National Research Council for their care and devotion to the details of arranging meetings and serving as an information center and command post while also producing and tracking an endless flow of working papers, report drafts, source materials, and correspondence.

The views, conclusions, and recommendations expressed in this report are entirely those of the STAR study members and should not be construed to represent the views of the Army or the Army liaison personnel.

Acknowledgments

This report is the work of Health and Medical Systems Panel of the study on Strategic Technologies for the Army (STAR). The panel's task was to address the issues of health, disease, and injury that U.S. Army personnel will face in the decades ahead. Also included in the report are assessments of research and technology developments that, in the panel's judgment, will be required to meet the challenges of military medicine in the twenty-first century.

Support from National Research Council staff of the STAR study was a major factor in whatever success the panel achieved in writing this consensus document. In particular, Ann Stark provided staff leadership. As both project officer to the panel and administrative coordinator for the entire STAR effort. Ms. Stark took special interest in the Health and Medical Systems Panel, and her impressive insight and understanding of health issues, coupled with her knowledge of the activities of the other STAR systems panels and subcommittees, were invaluable. She helped the panel focus on its activities and provided encouragement when progress flagged. Margo Francesco, Kelly Norsingle, and Latricia Cox also provided the panel with excellent and enthusiastic project support.

The Army Liaison Personnel assigned to this effort, Colonel Steven Hursh and Colonel Robert Mosebar (U.S. Army retired), were active contributors. Their dedicated participation helped clarify the specific needs and problems of the Army during peace and war and enlarged our perspective. The panel members readily accept full responsibility for the firm recommendations in this report. The product, after many months of deliberation, nonetheless, strongly reflects the scholarly contributions of our able, likable, and wise Army liaison personnel.

All members of the panel required additional information to overcome a steep learning curve. Many agencies, organizations, and individuals went to considerable effort to assist us with good grace and often extensive instructional programs. The panel noted a justifiable pride in those individuals for their contributions to progress in Army health and medical affairs. The panel would be remiss if it did not cite the valuable information and orientation it received through visits to the U.S. Army Medical Research and Development Command, Fort Detrick, Maryland; the Walter Reed Army Institute of Research, Washington, D.C.; the U.S. Army Health Services Command's Academy of Health Services at Fort Sam Houston, San Antonio,

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Texas; and the Chemical Research, Development and Engineering Command, Aberdeen Proving Grounds, Maryland¹

The Health and Medical Systems Panel dedicates this report to the U.S. Army Medical Corps. They have been the leaders in the art and practice of military medicine and, through research, development, and application, have made notable contributions to all of humankind.

¹ There were a number of texts, as well, that the panel used as general references throughout the writing of this report. These were (U.S. Army, 1985); (IOM, 1985); (NAE and IOM, 1988); and (NRC, 1987).

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Executive Summary

BACKGROUND

In March 1988, John R. Sculley, Assistant Secretary of the Army, Research, Development and Acquisition, requested that the Board on Army Science and Technology conduct the Strategic Technologies for the Army (STAR) study. The STAR study was intended to recommend a direction for technology development by the U.S. Army over the next 20 to 30 years. The study was organized into several groups that addressed science and technology, technology management and development planning, and systems capabilities. The Health and Medical Systems Panel was one of the eight STAR systems capabilities panels.

The systems panels identified possible future systems based on the Technology Forecast Assessments of the STAR study's technology groups and recommended Army research and development (R&D) efforts that would support the development of these systems. The systems panels also provided insight into the consequences of these projected systems on the Army of the future, including on its force structure, doctrine, and strategy. The Health and Medical Systems Panel depended heavily on the knowledge and military experience of its assigned Army liaison personnel.

This is the final report of the Health and Medical Systems Panel. The panel focused primarily on future advances in medical and surgical care that will have an impact on the prevention and treatment of disease and injury during peacetime and war. Such future advances will stem from the application of new biotechnologies that derive from the life sciences.

HISTORICAL FRAME OF REFERENCE

One hundred years ago the introduction of sanitation of food and water supplies and other hygiene measures represented the first major advance in medicine for the prevention of disease. Between 1900 and 1950, only the discovery and use of vitamins to treat vitamin deficiencies and of antimicrobial agents and antibiotics to treat infections had as dramatic an impact on medical practice as had the earlier introduction of sanitary procedures. But the pace of medical progress during the past 40 years has surpassed that of the previous 50. Although in 1950 it was an act of faith to believe that medical research would benefit humanity, few would have predicted the revolution in the treatment and prevention of disease that has occurred since then. Vaccines are now used to prevent polio, rubella, measles,

and hepatitis. Drugs exist that can treat hypertension, cardiovascular disease, and cancer as well as depression, schizophrenia, and other mental conditions. Surgeons perform cardiac surgery, use prosthetic devices to replace injured vessels and deformed joints, and transplant organs. New diagnostic devices make use of fiber optics, lasers, and positron emission tomography. Biotechnology allows large-scale production of a new family of drugs, such as interferon and interleukin, derived from the body's internal regulatory systems. These examples represent an expanding array of innovations that have changed the practice of medicine forever. Just as the practice of medicine today bears little resemblance to that of 40 years ago, the practice of medicine in the future will exceed the prophecies of today. And just as the medical advances of today are based on past research, the medical advances of the future will be based on the research that precedes it. The Army must prepare now for the future.

The opportunity for major advances in the biological sciences has never been greater. Knowledge about basic biological processes has grown exponentially during the past generation and will continue to do so during the next 20 to 30 years, the time frame addressed in this report. Technological advances in other areas, such as computers and instrumentation, will fuel new discoveries and new applications. This knowledge can be applied to both human welfare and human warfare. On the positive side, it creates new opportunities for Army medicine to sustain and protect the individual soldier, prevent and treat disease and injury, and preserve the fighting force. On the negative side, it may allow potential enemies to develop new chemical and biological weapons. For this reason, the Army must use new technologies to develop countermeasures against these new threats.

PLAN OF THE STUDY

The Health and Medical Systems Panel considered all major aspects of health, disease, and injury during peacetime and war 20 to 30 years hence. Within the context of advancing technology, it examined the responsibilities of the medical department of the Army at every stage in the career of a soldier, from initial-entry training through a career of service during peacetime and war.

The panel found that Army medical needs are not generally the concern of extant industrial and commercial organizations. For example, the national pharmaceuticals industry is almost exclusively directed toward civilian consumption. Therefore, to address medical needs unique to the soldier, it is necessary for the Army to maintain the programs it has in place.

The panel considered a wide range of technical innovations that are likely to occur during the next 20 to 30 years and that will enhance the ability of the Army's medical department to maintain the health and fighting

capability of a soldier by preventing and treating diseases and injuries. The panel paid close attention to those technologies that are applicable to each stage in the career of a soldier, including events during and after injury on the battlefield. It also considered possible technical innovations that will enhance all aspects of medical support during war, including casualty location on the battlefield, treatment, evacuation, and a medical system in the field that would expedite the return of sick and wounded soldiers to active duty. Such a medical system will require a coordinated chain of medical care that begins with the care provided by the combat lifesaver at the site of injury on the battlefield, continues with the medical corpsman at the forward aid station, and proceeds to the larger medical facilities in the rear.

EVALUATION OF MAJOR ILLNESSES AND DISABILITIES IN THE ARMY DURING WAR AND PEACE, NOW AND IN THE FUTURE

The panel reviewed the most frequent causes of casualties and disabilities during World War II, the Korean war, and the war in Vietnam. These were (1) infectious diseases, including diarrhea; (2) dehydration; (3) penetrating wounds and blast injuries with severe hemorrhage; and (4) psychological and physical combat stress. Although casualties caused by burns were important because they required intensive medical and surgical care, they were not among the major causes of disability and death. The panel recognizes that burns could become a serious concern in the future if the nature of offensive weapons changes. It is likely, though, that the causes of disabilities and casualties listed above will remain significant during the next 20 to 30 years. The Army should bring emerging technologies to bear on methods of minimizing the occurrence of disease and injury, develop better methods of prevention, and improve surgical and medical treatment.

The panel also examined the threats of chemical and biological warfare. It noted that there will be new technologies to detect and neutralize these threats and to treat the soldiers and civilians that may be injured if these methods of warfare are used. This topic is discussed in detail in the biotechnology and biochemistry section of the STAR Technology Forecast Assessments volume (NRC, 1993a).

PRIMARY GOAL

The primary goal of the U.S. Army should be to improve Army Medical Corps capabilities by strengthening Army R&D programs for medical systems in support of the individual soldier.

CONCLUSIONS AND RECOMMENDATIONS

It will be essential for the soldier of the future to maintain a high level of cognition and good health to cope with increased demands to learn and retain technological skills. Therefore, as stated in Chapter 1 of this report, it will continue to be necessary for the individual soldier to maintain good physical and mental health in order to increase performance during the course of his or her career. The Army of 2020 will be able to meet the challenge of preventing disease and injury by implementing the following panel recommendation:

Strengthen and promote R&D in the biomedical sciences to increase understanding of the physiology of physical fitness; psychobiology and neurosciences related to cognitive abilities, motivation, and mental health; and pharmacology and biotechnology leading to the development of new vaccines and antimicrobial agents.

The future soldier will be exposed to a wide array of new high-technologies, as well as existing threats as described in Chapter 2. To adapt to this changing battlefield, the Army of 2020 will have to continually devise new methods of dealing with these threats in addition to improving present countermeasures. The panel suggests that the following recommendation be implemented:

Enhance battlefield threat assessment and response by supporting R&D in biotechnology that would improve methods for early detection, identification, and countermeasures to prevent or neutralize the adverse effects of chemical, toxin, or biological threats; counter nuclear and directed energy threats; and provide the means to reduce risks from environmental hazards.

Chapter 3 of this report describes how the projected threats on the battlefield of the future will require improved methods of medical prevention and treatment. Special devices and procedures designed to provide enhanced protection from, and immediate treatment for, injuries resulting from direct enemy action and environmental threats will be required. The panel therefore encourages the Army to implement the following measure:

Accelerate and support R&D on the integrated soldier protective system; on field medical systems by emphasizing mobility and resuscitation at far-forward positions; and on novel replacements, such as skin grafts, artificial blood, and fluid substitutes.

To enhance their required supporting capabilities as described in Chapter 4 of this report, the Army will have to take full advantage of advances made in the civilian and commercial sectors (e.g., hospitals, universities, and laboratories). It will have to monitor programs and research in these sectors, collaborate and integrate developments, and in some cases adapt and harden these developments for use on the battlefield. The panel suggests that the Army maintain and enhance its required supporting capabilities by strengthening its medical R&D infrastructure through the following actions:

1. *Emphasize the necessity for U.S. Army medical R&D and for the recruitment and retention of medical research personnel.*
2. *Develop trauma centers for research, treatment, and patient care.*
3. *Develop a center for biobehavioral research for the prevention and treatment of psychiatric illnesses and conditions; the study of sleep deprivation, stress, and behavior modification; and training and cognition in war and peacetime.*
4. *Maintain U.S. medical R&D in overseas laboratories to detect the early occurrence of microbial diseases and chemical, toxin, and biological warfare (CTBW) threats.*
5. *Develop and strengthen collaborative relationships among universities, industry, and the Army in laboratory and clinical research. This would make new technologies available for Army medical research with emphasis on the treatment of trauma, infectious disease, neurobehavioral science, and molecular biology.*

Finally, to ensure the performance enhancement, sustainability, and survivability of the individual soldier, the Army must continue to monitor all future prospects and advances in science and technology. The panel suggests that establishing a soldier integration steering committee to coordinate parallel R&D efforts and insert modules into the system design might prove advantageous. To maintain the technology edge and exploit relevant technologies, the Army should:

Invest in and develop resources capable of identifying and adapting emerging technologies to the medical needs of the Army, especially the individual soldier. This may be achieved by stressing more effective use of computing systems and high-speed data-processing techniques for medical data management, modeling, and display technology, all of which will aid and enhance research and analysis.

Prevention of Disease and Injury

The importance of the individual soldier and his or her capabilities is crucial in a future that is increasingly dependent on advancing technologies. In large part, success or failure in war and peacetime depends on the ability of the individual soldier to perform well physically and mentally and to integrate the capabilities and demands of the future. Advances in the medical and behavioral sciences will create new opportunities to increase the pool of potential soldiers, sustain them, and enhance their ability to perform.

As the skills of the soldier increase with the application of new technologies, a primary consideration will be to maintain the health and performance capabilities of this highly trained individual for an entire career. In doing so, the Army has the opportunity to apply the principles of preventive medicine, including, for example, better nutrition, physical training, favorable life-style changes (e.g., no smoking, moderate drinking), optimal medical care, and minimization of the risks of the military environment (e.g., accidents, noise, fumes, and toxins). Furthermore, as knowledge about the biology of aging and development increases, it may be possible to predict and modify the genetic factors that influence the natural life span and to promote favorable changes in endurance, strength, and perceptual and cognitive functions during a soldier's later years of military service.

IMPACT AND NEEDS

New methods to achieve physical and mental fitness of Army personnel and to prevent disease will be needed to improve and maintain the health of the soldier during initial-entry training and throughout a career in the Army.

Prevention efforts should include the creation of new methods to improve physical and mental fitness and the development of new vaccines to prevent infectious diseases (including those caused by parasites).

Impact on the Command Structure

The impact on the command structure will be to increase to a high degree the combat readiness of the individual soldier, decrease the occurrence of preventable illness and injury as a cause of absence from duty, and decrease the need for replacement personnel.

Impact on the Medical Department of the Army

The impact on the medical department of the Army will be to decrease the number of hospital admissions. This will be achieved through the use of vaccines to prevent infections and the avoidance of injuries caused by inadequate physical or mental fitness. It will reduce the requirement for professional medical and support personnel and for medical treatment facilities.

PHYSICAL AND MENTAL HEALTH ENHANCEMENT

Once the soldier begins active duty, he or she must be trained to meet rigorous physical standards and high levels of capability. At least two issues should be considered:

1. The ordinary soldier who meets the Army's entrance criteria must be prepared for readiness. There is a possibility that new advances from the biomedical and behavioral sciences will be able to enhance physical and psychological fitness, promote learning and performance, and maintain health over a soldier's entire military career.
2. Advances in biomedical and behavioral sciences may salvage a significant number of persons who are currently excluded from military service because of physical or psychological problems. For example, new treatments might enable diabetics, hypertensive individuals, or former drug addicts to serve in the military successfully.

In terms of physical fitness, considerable progress has been made in recent years in preventive and sports medicine. At the level of competitive sports, methods of physical training have pushed world records to higher and higher standards. At a societal level, there has been renewed interest in physical fitness, nutrition, and a healthy life-style; these have been partially credited for falling rates of cardiovascular disease. In addition, techniques of physical training based on physiological and biomechanical principles are advancing, as is the capability to assess and measure physical performance (i.e., kinesthesia). The ability to prevent and correct certain types of injuries also is increasing. And while pharmacological performance enhancers (i.e., anabolic steroids, stimulants) have been justly condemned due to concerns for safety, ethics, and sportsmanship, in the future new pharmacological agents might be developed that will be relatively safe and will increase physical strength, endurance, recovery, and performance. These emerging technologies offer the opportunity to enhance and prolong physical and mental health.

As more is learned about the clinical neurosciences and cognitive sciences, it may be possible to predict and enhance specific higher functions

of the nervous system, such as perception, attention, motivation, learning, and memory. It can be anticipated that progress might come from new methods of learning (e.g., computer-directed teaching programs based on a better understanding of cognitive processes), as well as from advances in the neurosciences, which might use new pharmaceutical agents to promote learning and memory.

PREVENTION AND TREATMENT OF INFECTIOUS DISEASES

Despite sanitary measures, water purification, and a major immunization program, infectious diseases remain a major cause of incapacity during initial-entry training and, indeed, even during combat. For this reason, new technologies should be applied to the development of vaccines to prevent diseases and new drugs to treat them.

Challenges for Future Vaccine Development

Vaccine development has been painstakingly slow since the *modern* successes with vaccines for polio, rubella, measles, and hepatitis B. Indeed, there are no more than 15 vaccines currently used by the Army, and yet there are at least 50 to 100 different microbes that cause excess morbidity and, in some cases, mortality. Respiratory and diarrheal diseases remain the two major causes of disability during wartime. And although sanitation measures involving potable water and prepackaged foods can diminish the threat of diarrheal diseases, new vaccines will still be one of the most effective ways to prevent infectious diseases in training centers and on the battlefield.

Accelerating the development of new vaccines will require both close examination of microbes to determine their pathogenic mechanisms and development of vaccine strategies to counteract these mechanisms. In addition, strategies for vaccine development must embrace new knowledge regarding the immune system. This includes information about the generation of immunity; the preservation of immunological memory; and the regulation or modulation of immune functions, including enhancement and suppression. Finally, new vaccines or methods of passive immunization may use specific antibodies, antibody hybrids, and antibody fragments.

There are at least three microbiological reasons why vaccine development has been delayed. First, in many instances, those critical microbial factors that account for virulence have not yet been clearly identified. Until these factors are known, it often is not possible to develop a vaccine (e.g., anticapsular vaccines use a capsule of pneumococcus and tetanus toxin vaccines make use of tetanus toxins). Second, many microbes, particularly viruses, occur as various distinct antigenic types. Immunity to one

type provides no protection against the other types. For example, the common cold is caused by over 100 different rhinoviruses and other respiratory viruses. Finally, some microbes have the power to diversify and elude natural or acquired immunity and to develop resistance to antibiotics. Indeed, the very course of a disease such as relapsing fever is due to the emergence within the patient of an immunoresistant form of the pathogen. This relapsing phenomenon is also seen in patients with malaria.

Future progress will depend on greater understanding of the pathogenic mechanisms of infectious diseases. Indeed, for example, until recently little was known about this matter with regard to *Staphylococcus aureus*, a common cause of burn and wound sepsis. In addition to ignorance concerning the pathogenesis of the common microbes that cause disease in the United States, there is even greater ignorance regarding the pathogenesis of parasitic diseases and other infections that thrive beyond U.S. borders but that are now and will be a threat to the health of Army personnel. In those few cases in which resources have been mobilized to investigate the pathogenesis of a particular disease with all the tools of the new biology, the results have been truly remarkable (e.g., regarding Korean hemorrhagic fever, Lyme disease, arthritis, acquired immune deficiency syndrome (AIDS), kuru, and Marburg disease). Any strategies for prevention, vaccine development, and/or treatment require information on microbial pathogenesis. There is no area full of more potential promise than the one that applies modern science to determining the pathogenesis of infectious diseases and uses this knowledge base to devise new interventions for the treatment and prevention of disease.

Development of New Drugs for the Treatment of Infection

Viral Diseases

Viral diseases (those caused by adenoviruses and coxsackieviruses, such as influenza and the common cold) are still the most common cause of incapacity. Because there are hundreds of these viruses, it is unlikely that they will all be prevented by vaccines in the next 20 years. Just as antibiotics to treat bacterial infections are relatively new, until recently there were no drugs to treat viral infections. However, a rational approach to antiviral drug therapy is now under way, in part as a response to the reemergence of sexually transmitted diseases and AIDS.

Since viruses use many of the host cell's synthetic pathways for replication, it is often difficult to inhibit viral replication without affecting the host. However, significant breakthroughs have been made in antiviral drug research. For example, the antiviral drug acyclovir is converted into a nucleotide by enzymatic phosphorylation only in cells infected with the herpes

virus. After acyclovir is converted into the nucleotide, it can exert its antiviral properties by selectively incorporating into replicating viral deoxyribonucleic acid (DNA), which inhibits viral multiplication. Since phosphorylation is a prerequisite to DNA synthesis, acyclovir is active only in cells infected with herpes virus. This mode of action limits the drug's potentially toxic effects on uninfected cells.

This breakthrough is a particularly instructive example of a new rationale for drug design. Certainly, this type of approach, coupled with new methods to determine the three-dimensional structures of proteins, including the active sites, will facilitate the design of new antiviral compounds for the treatment of common viral diseases, as well as lethal infections such as encephalitis and AIDS.

Parasitic Infections

Another area of great potential is the development of new drugs for parasitic infections. It is now clear that the application of cellular and molecular biology as well as physiology and pharmacology will reveal the fundamental pathogenic mechanisms that have thus far escaped detection. Can sexual union of parasites be prevented and thus prevent propagation of disease and transmission to a susceptible host? Can growth and development of parasites be arrested so that defense mechanisms of the host arrest the infection? Ivermectin, for example, for the treatment of river blindness, appears to interfere in some way with the gamma amino butyric acid system of the parasite, with the result that the uterus of the parasite remains flaccid and the microfilaria are not extruded but degenerate *in utero*. It is likely that further research on the physiology and molecular and cell biology of parasites will lead to other effective drugs for the treatment of the major parasitic diseases, such as malaria, schistosomiasis, and leishmaniasis.

Prevention of many infectious diseases (particularly, but not exclusively, in the tropics) depends on the control of insect vectors. Here, again, methods that remain beyond our grasp will emerge from the intensive new effort in biology—in this case, the biology of insects. Little attention has been devoted thus far to the infectious processes of the parasite within the insect vector. It may prove possible to block maturation of the infectious forms of the parasites within the insect and thus prevent transmission. Another avenue of promise concerns the immune system of mosquitoes, where it may prove possible to enhance the insects' immunity and thus terminate infection and block vector transmission.

CONCLUSIONS AND RECOMMENDATIONS

It will be essential for the soldier of the future to maintain a high level of cognition and good health to cope with increased demands to learn and retain technological skills. Therefore, it will continue to be necessary for the individual soldier to maintain good physical and mental health in order to increase performance during the course of his or her career. The Army of 2020 will be able to meet the challenge of preventing disease and injury by implementing the following panel recommendation:

Strengthen and promote R&D in the biomedical sciences to increase understanding of the physiology of physical fitness; psychobiology and neurosciences related to cognitive abilities, motivation, and mental health; and pharmacology and biotechnology leading to the development of new vaccines and antimicrobial agents.

The Changing Battlefield

Before the panel considered new threats to soldiers on a high-technology battlefield, it reviewed trends from past wars to gain insights into the likely medical requirements for soldiers in the battlefield of the future. The panel found that although the nature of wounds may change, certain medical imperatives will continue to focus on medical technology.

The risk of death on the battlefield has steadily decreased since the Civil War. It is clear that the art of war and improvements in casualty evacuation have had a dramatic impact on the protection of the average soldier. Figure 2-1 shows that the percentage of all soldiers committed to the theater of battle who died on the battlefield decreased from 6.5 percent in the Civil War to 0.7 percent in Vietnam, a tenfold decrease. The most dramatic impact is evident in the reduction of deaths in the hospital, from nearly 10 percent of the troops committed to the war zone during the Civil War to less than 0.05 percent for troops serving in Vietnam. There was a reduction in the percent killed on the battlefield as well, and this can be attributed to greater dispersion of troops, improved protective equipment, improved training of combat medics, and increasingly rapid evacuation and improved evacuation techniques.

The majority of deaths in the hospital during the Civil War, World War I, and World War II were caused by disease rather than battle wounds. Preventive medicine, first practiced during World War I and enhanced in World War II, dramatically decreased hospital deaths attributed to disease. It reversed the ratio of deaths in the hospital, with battle wounds rather than disease becoming the greatest cause of death. Improved medical and surgical treatments both prior to and during hospitalization have contributed significantly to decreased hospital mortality (see Figure 2-1).

Also noted in Figure 2-1 is reversal of the comparison between the risk of death in the hospital and that in the battlefield. Most deaths in the Civil War and World War I occurred in the hospital, whereas the majority of deaths in World War II, the Korean war, and the war in Vietnam occurred on the battlefield. Even though disease is the major cause of hospital admissions and noneffective days during war, it is no longer the leading cause of hospital mortality.

Today, fewer soldiers are killed in action but, relative to the mortalities, more are wounded (see Table 2-1). There has been a steady decline in the proportion of all troops killed in action. This reflects, in large measure, improved evacuation methods, especially helicopters dedicated to evacuating casualties. However, this rapid evacuation process has brought into

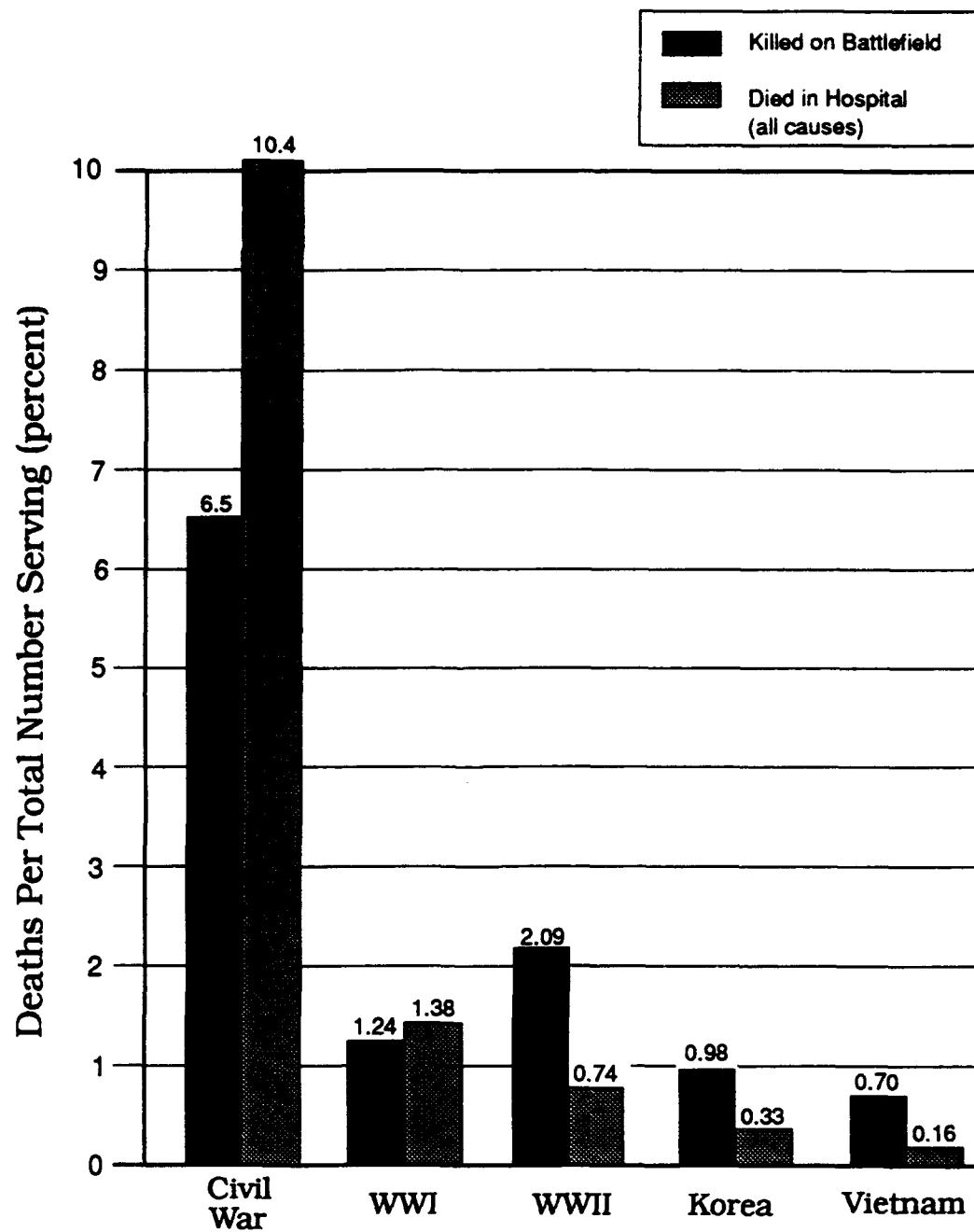


FIGURE 2-1 Risk of death during war (1860–1970).

the medical system an increasing number of severely wounded individuals who might have died on the battlefield in earlier wars. Progress in preserving the lives of severely wounded troops has lagged, primarily because of the ongoing need to improve far-forward resuscitative procedures on the battlefield, at the aid station, and during transport. This problem has not improved since the Korean war.

TABLE 2-1 Ratio of Troops Killed in Action to Those Wounded in Action

	World War II	Korea	Vietnam
Killed in action: wounded in action	1:3.1	1:4.1	1:5.0

The major components of disease-related admissions during war have not changed since World War II. Figure 2-2 shows the five major categories of the causes of disease contracted by combat soldiers during World War II and the wars in Korea and Vietnam. The five categories have remained the same in these wars. It is not appropriate to draw strong conclusions about changes among the disease categories throughout those wars because the different geographic locations of the conflicts played a large role in the presence of disease. In general, however, the highest rates of occurrence were in the respiratory and gastrointestinal categories. The rate of infectious or parasitic diseases also remained high and was the highest in the Vietnam war because of the geographic location of the conflict. Rates of neuropsychiatric disease are likely to be higher than 5 percent in the future because of the anticipated increase in the complexity and highly technical nature of future conflicts. Rates of neuropsychiatric diseases probably underestimate the true incidence of such problems because they may not be manifested completely while the soldier is hospitalized.

The vast majority of hospital admissions during combat are not due to battle injury but are from disease. A review of the nature of hospital admissions since World War I indicates that the proportion of total admissions due to battle injury increased from 5 percent in World War II to 24 percent in the Vietnam war. However, the majority of admissions were still attributed to disease (82 percent in World War II and 62 percent in the Vietnam war; see Figure 2-3). The remaining admissions were due to nonbattle injuries and exhibit no stable trend (see Table 2-2).

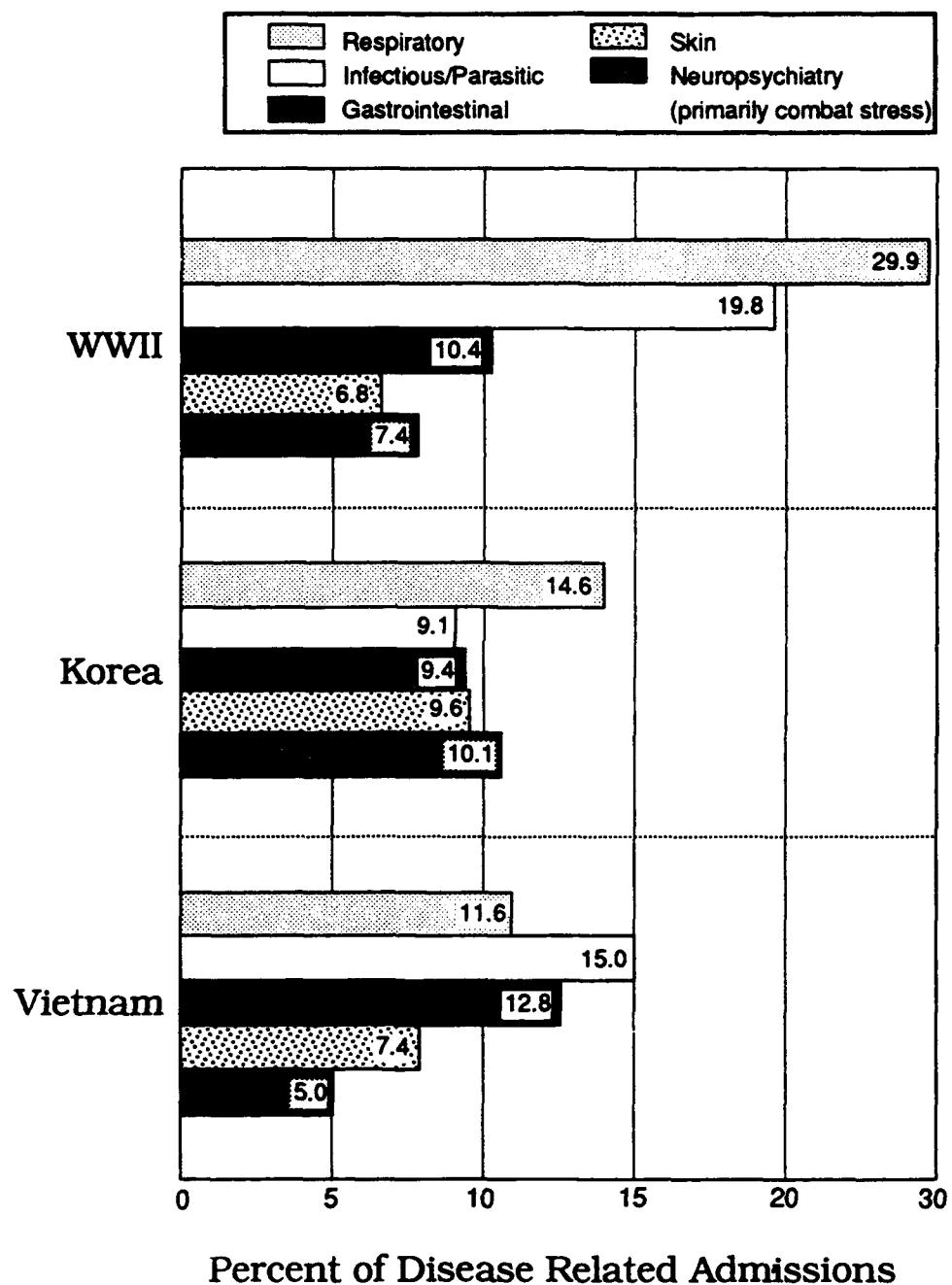


FIGURE 2-2 Leading causes of disease-related hospital admissions during three wars.

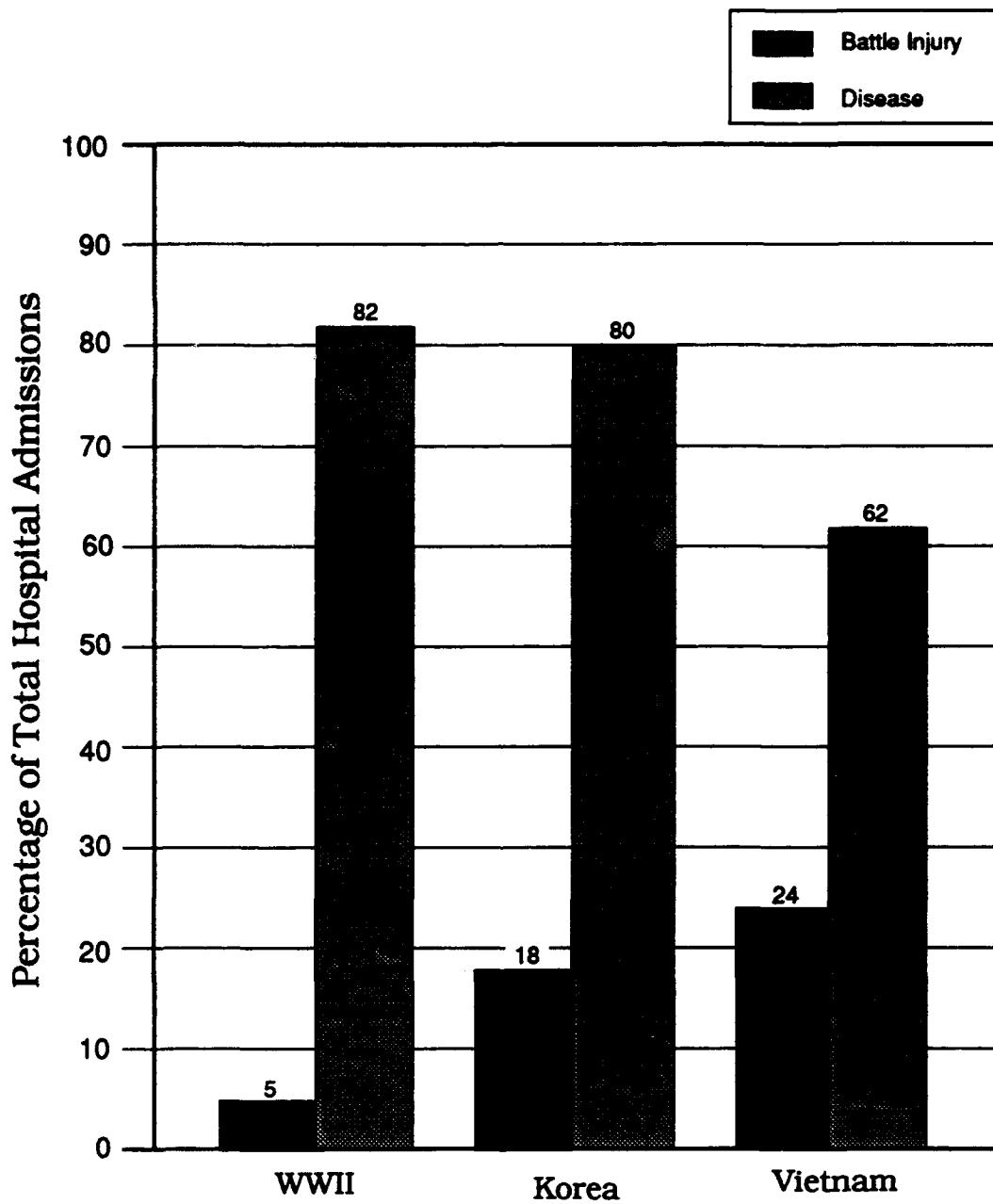


FIGURE 2-3 Proportion of hospital admissions from battle injury and disease during three wars.

TABLE 2-2 Major Components of Hospital Admissions During Three Wars

Percentage of Total Hospital Admissions				
	Total Number of Hospital Admissions	Battle Injury	Nonbattle Injury	Disease
World War II	17,664,641	5.0	13.0	82.0
Korean war	443,163	17.6	2.4 ^a	80.0
Vietnam war (1965-1970)	391,879	24.0	14.0	62.0

^aThis seemingly low figure probably reflects reporting of many nonbattle injuries in the disease category.

SOURCE: U.S. Army, (1982).

It should be noted that, especially in more recent conflicts, there has been a decrease in the number of hospital admissions as compared to the total troop strength engaged in a conflict (see Figure 2-4).

A careful review of Figure 2-4 indicates that the incidence of combat troops contracting a disease that necessitated a hospital admission declined steadily from World War II to Vietnam. This is a reflection of the fact that, increasingly, disease is more likely to be treated on an outpatient basis than as a hospital admission. However, the incidence of combat wounds that required admission to the hospital remained unchanged. In Desert Shield and Desert Storm the incidence of disease and battle wounds requiring hospital admission was so low that it was relatively incomparable.

HIGH-TECHNOLOGY WEAPONS

New technologies for weapons systems, communications, power generation, surveillance, and target acquisition introduce the potential for new environmental and health hazards. For example, various forms of electromagnetic pulse (directed energy beams), such as radio frequency, laser, high-power microwave, and particle beam, pose potential health risks whose assessment has only just begun and against which there currently is inadequate protection. New propellants and combustion processes yield chemical by-products that can be environmental and health risks. High-energy

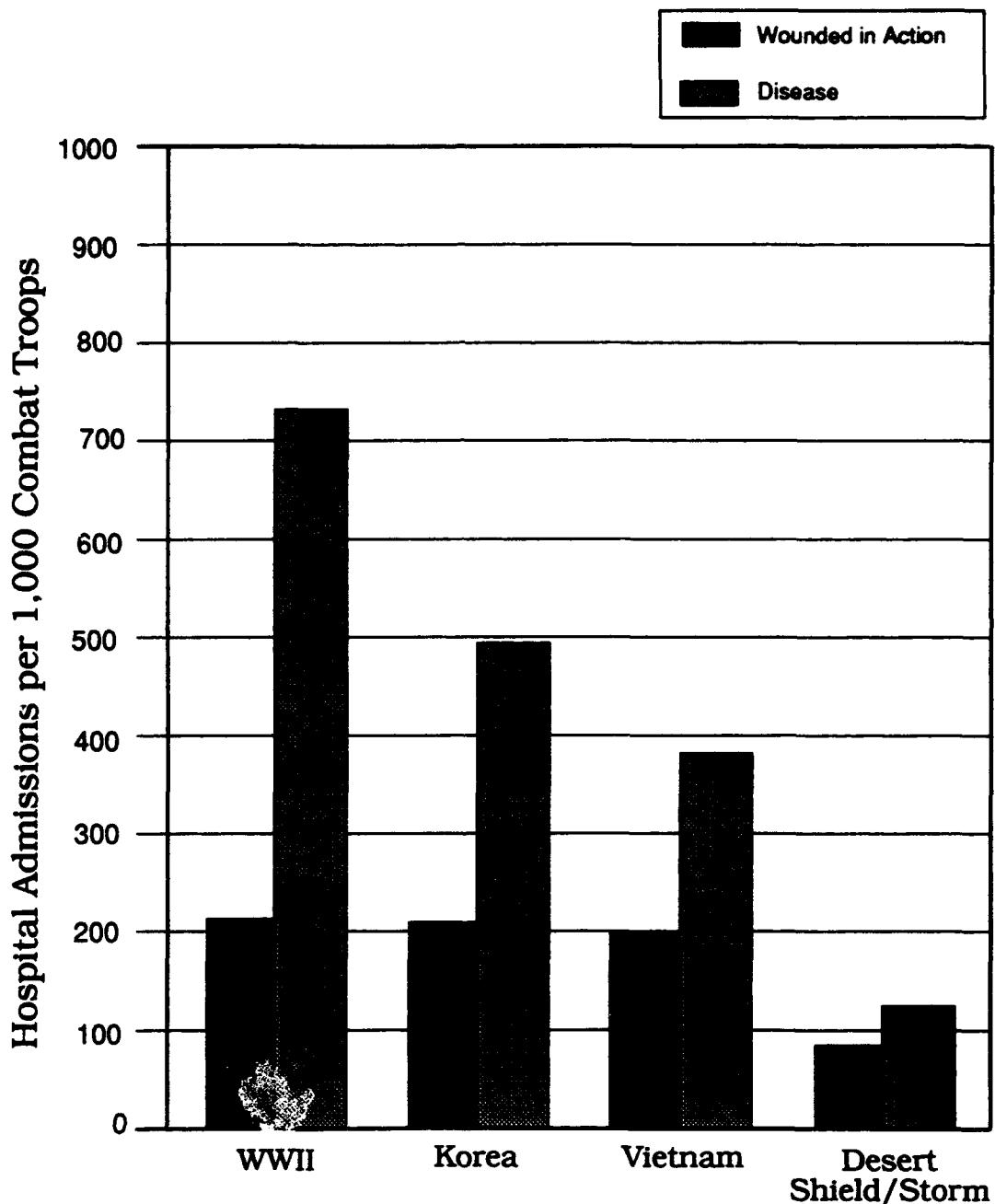


FIGURE 2-4 Incidence of hospital admissions for diseases and for wounded in action per 1,000 combat troops during four wars.

explosives produce shock waves with known risks that must be controlled. New equipment to extend or protect the capacity of the soldier also can increase the soldier's burden (see the STAR Special Technologies and Systems Panel report for an in-depth discussion of this problem (NRC, 1993b)). Finally, the high-intensity, silent, invisible threats of future weapons will challenge the psychological endurance of the future soldier.

Modern weapons emit energy sources that can cause damage to human visual and auditory systems. Lasers used for rangefinding, target identification, and designation may cause irreversible anterior and posterior eye lesions. These lesions will be particularly incapacitating when the beam is directed at the fovea of the eye. This occurs when the victim looks directly at the source. In the future, as the power frequency and sophistication of such weapons increase, new methods for eye protection will be essential. Means must be devised to identify instantaneously the wavelength of the incoming energy (with a tunable laser from the ultraviolet to the infrared range) and, using the vision protection system, to automatically occlude the transmissibility of that energy. This must be done without restricting the normal vision requirements of the soldier. Given the rapid advances in, and variety of, electronic sensors and electro-optical materials, such a capability seems achievable.

Protection of the auditory system is necessary today, but the battlefield of the future will be filled with even more complex airborne and other sounds. These sounds will be complex in terms of ranges of magnitude and frequency, and protection will be of the utmost importance to the well-being of the individual soldier. Passive ear canal restrictors and filters will be augmented by active sound cancellation systems, which generate negative versions of the incoming noise. When this *antinoise* is superimposed on the incoming noise, it cancels the wave energy impinging on the eardrum. Advances in batteries and microelectronics will make such systems an integral part of the soldier's headgear.

IMPACT AND NEEDS FOR ASSESSMENT OF HEALTH HAZARDS

Assessment of health hazards is the responsibility of the surgeon general of the Army. However, responsibility for incorporating this assessment into system planning and budgeting must rest with the system developer. Therefore, the process must be a partnership. The system planner must initiate the medical assessment at the earliest possible time in the development process to minimize the cost of incorporating that knowledge into the system's design.

The assessment of health hazards will be a major driver of basic medical research. The potential biological hazards of new systems technology will require a matching investment to investigate the energy and chemical threats on the battlefield. A generic effort in basic science to assess broad

categories of hazards should be an integral part of the future medical technology base; system-specific assessments will then supplement that base in response to the proposed next generation of systems and future systems. This will be done on the basis of a close partnership between the medical community and system developers.

Both old and new battlefield threats demand assessment and response capabilities essential to both the command and the medical organizations, as delineated below:

- *Command.* Identification of threats by considering both organized warfare and terrorist action is essential to the medical consequences of battle and the mounting of appropriate responses.
- *Individual soldier.* Identification of threats is essential for determining protective measures for the deployment of troops.
- *Medical impact.* Although medical impacts are applicable for both current and foreseeable threats, the unique aspects of different threats warrant separate discussion.

THREATS FROM NUCLEAR, BIOLOGICAL, AND CHEMICAL WEAPONS

Threats from nuclear, biological, and chemical weapons have long been recognized. The capacity to isolate organisms and formulate extremely lethal chemicals far exceeds the current capacity to devise acceptable preventive or therapeutic medical interventions. Physical protection is often highly effective, but it introduces severe limitations on the performance of a unit. Nuclear, biological, and chemical threats are most often associated with the most sophisticated military establishments, but recent developments indicate that these weapons have proliferated to groups in power in less developed countries. In fact, certain biological and chemical weapons can be used more cost effectively by nonindustrialized countries than modern conventional weapon systems. This cost factor, in addition to the potential for terrorist use of these weapons, clearly makes these weapons a future threat.

Defense Monitoring of Chemical and Biological Threats

The challenge for technology is threefold: (1) to protect soldiers in advance; (2) to detect and identify an agent when it is used; and (3) to apply medical prophylaxis, therapeutic interventions, or both.

Protection will involve the combination of minimally intrusive, external physical barriers with a select group of generic physiological protective barriers, either immunological or passive scavenger protective. This approach

is important, but it is necessarily incomplete given the wide assortment of potential threats and the expanding means of production.

Rapid detection and identification of a threat will be necessary and highly feasible in 20 to 30 years and will allow the application of very specific medical interventions. In the case of biological agents with a delayed onset of effect, this approach can be very effective in protecting a unit's capability, provided that the medical intervention is readily available. Detection and identification of a threat will capitalize on advances in biotechnology and automation in such a way that very specific identification of an agent should be possible from minute samples. In fact, a sufficiently rapid and inexpensive methodology would make it possible to conduct continuous monitoring for biological and chemical weapons agents in order to ensure the earliest possible detection and intervention.

It is expected that much of the basic technology necessary for detection and identification of biological and chemical agents will be developed for civilian clinical applications. However, military researchers and developers will need to tailor that technology for military-specific threats and miniaturize and harden it for field use.

To render the definitive diagnosis of biological disease in human samples, medical laboratory diagnostic facilities at the corps or theater level will augment chemical and biological detectors operated by nonmedical combat units at forward positions.

This laboratory facility must also have the capability of detecting biological warfare agents used by the enemy. Here the Army has a unique and specific role to play. The limiting factor will be full understanding of the genetic composition of all relevant infectious agents, including those components that identify certain strains as being especially virulent. Subsequently, it will be necessary to produce probes for each agent and each virulence factor. Much of this work will be done in the civilian sector that deals with common infections. However, many of the risks to the military are not present in the United States, so these infectious agents must be studied and probes must be made through Army research and development (R&D). Army-specific R&D is also needed for such special problems as biological warfare agents that can be presented in a genetically altered form and therefore elude conventional polymerase chain reaction (PCR) detection. PCR technologies will be enhanced by automation and robotics.

The information gained from chemical and biological detectors and medical diagnostic tests will trigger specific medical interventions. For certain classes of known chemical and biological threats, prearranged therapies and prophylaxis may be carried by the soldier or the combat medic. Therapies already exist for injuries caused by nerve agents; others are under development for classical agents such as cyanide and mustard gas.

Given the potential for a variety of new chemical and biological agents, it may not be possible to have large prepositioned stocks of antidote for each

threat. Instead, advances in biochemical synthesis and sequencing may make it possible to stock a relatively small number of fundamental ingredients, which may be sequenced or cloned near the battlefield by automated means and use of prearranged recipes, to address a variety of threats. This flexible approach, combined with certain generic antiviral drugs and immune system enhancers, may provide a highly effective medical barrier to chemical and biological threats.

Further discussion of chemical and biological threats and countermeasures can be found in the STAR Technology Forecast Assessments volume in the chapter on biotechnology and biochemistry (NRC, 1993a).

Nuclear Threats

Radiation exposure can produce bone marrow destruction before other essential tissue and organ functions are impaired. After bone marrow destruction, bone marrow growth factor, such as granulocyte and monocyte colony stimulating factor, will encourage growth and recovery of any few remaining blood stem cells in the marrow. In a nuclear war a large number of casualties would be salvageable if bone marrow recovery were possible. In the future, growth-factor-containing pharmacological agents will be used to hasten the soldier's return to duty by stimulating bone marrow production.

It should be possible to collect stem cells from the peripheral blood for storage and eventual reinfusion into radiation-exposed casualties. Ordinarily, few stem cells are found in the blood. However, the use of growth factors now makes it possible to produce a burst of stem cells in a normal individual. These cells can then be collected by a relatively safe and innocuous cell pheresis technique. Such stem cells could be collected from soldiers at risk of exposure to high levels of radiation or from those who possess special qualifications for missions that would put them at risk. Stem cells could be gathered from the soldier prior to his or her mission and stored by cryobiotechnological techniques (similar to those used to freeze blood). If the stem cells are reinfused during the first week of radiation exposure, lives could be saved, and in some cases casualties could be returned to duty. For the problem to be solved, additional biological information on stem cell growth and the distribution of stem cells in peripheral blood, as well as the long-term competence of these cells, should be obtained. With the development of new tissue-typing methods, it may be possible to have a pharmacy of stem cells that could be used to treat any radiation casualty. Even if tissue matching were not possible, it is feasible that a repository of autologous blood stem cells could be established for storage and individual reinfusion.

INFECTIOUS DISEASES

The protection of troops from infectious diseases will depend on a detailed understanding of the microbe present in the combat zone. It is unlikely that all troops can be treated for protection against all potential disease threats. Therefore, surveillance of infectious disease agents in the fighting area will be necessary. Two levels of surveillance need to be perfected.

General surveillance of potential areas of conflict should include on-site microbiological observations and detection, advanced detection devices for microbial threats, and satellite evaluation of geographical and environmental changes that promote the occurrence of infection and disease, including their cycles of occurrence. Disease surveillance must also be carried out during combat and, ideally, should be available on the front lines.

Estimation of temperature, humidity, and other factors by satellite sensing and observation should allow for modeling of the cycles of vector growth (such as that of mosquitoes) as well as the conditions for growth of viral, bacterial, and fungal disease agents. Also, more specific examination of the epidemiology of infectious diseases should be possible through the development of rapid diagnostic facilities for detection of the specific genetic core of each of the major infectious organisms that pose a threat.

New technologies such as PCR make it possible to detect minute quantities of microbes with extreme specificity. It should be possible to automate these procedures to sequentially probe samples of air, water, soil, etc., for all important infectious agents. Because up to 70 percent of all casualties in a conflict can be due to upper respiratory infection and diarrhea, using PCR regularly to monitor hot spots in the world can prepare troops to resist local infections. Vaccines, antibiotics, and antiviral agents could then be administered before exposure occurred, thereby minimizing the loss of troop effectiveness.

NEUROPSYCHIATRIC THREATS

One of the top five disease categories resulting in hospital admissions is neuropsychiatric disorders (see Figure 2-2). This major cause of lost manpower during combat has traditionally been attributed to *combat stress*, *combat fatigue*, and *shell shock*. Other similar terms have been used to describe the condition. Furthermore, posttraumatic stress disorder has officially been recognized as an outgrowth of combat experiences. The high lethality of the future battlefield; the potential for the silent threats of chemical, biological, and directed energy weapons; the dispersion of troops; and the uncertainties of contingency operations promise to increase the importance of psychiatric prevention and treatment in future wars. Advances

in the social-psychological sciences will contribute to better organizational support for soldiers so that stress can be reduced. The high-technology *soldier computer* described in Chapter 3 will provide better location information and unit communication, which will serve to reduce uncertainty and stress. For those who become stress casualties, new pharmaceutical agents may reduce the typical recovery time significantly.

In addition to recognized hospital admissions for psychiatric reasons, there are many more *subclinical* cases of severe performance degradation caused by sleep deprivation, physical fatigue, and stress. This problem will be exaggerated in the future by the prospect of a round-the-clock operation resulting from the use of night vision devices. The effects of sustained operations and unusual sleeping-waking schedules are likely to be common problems on future battlefields, with detrimental effects on morale, performance, cognitive ability, communication, and judgment. Advances in behavior analysis and pharmaceutical agents with psychoactive effects will allow soldiers to obtain more efficient sleep during limited breaks in action, to perform more effectively after long periods of sleep deprivation, and to adjust more rapidly to changes in time zones during deployments.

ENVIRONMENTAL HAZARDS

Environmental extremes (extreme cold, heat, and high altitude) have frequently produced more combat casualties than any enemy force. Extremes of heat and cold severely complicate the management of wounded or injured soldiers, and altitude sickness can be fatal. Technology will provide micro-energy sources and devices for heating and cooling as circumstances require. These devices will be of a nonburdensome size and weight and will be available in all medical evacuation vehicles. Separate small protective "cocoons" will be technologically feasible for transporting combat casualties.

Altitude sickness will be prevented by medications and treated by miniaturized oxygen generators, thus allowing combat operations to take place in such high-altitude locations as the Andes in South America. With the reduction or elimination of environmental hazards, many soldiers may continue to function effectively in environmental extremes or be returned to duty sooner in order to preserve the fighting force.

CONCLUSIONS AND RECOMMENDATIONS

The soldier of the future will be exposed to a wide array of new high technologies as well as to existing threats. Therefore, in order to adapt to this changing battlefield, the Army of 2020 will have to continually devise new methods of dealing with these threats in addition to and improving present

countermeasures. The panel suggests that the following recommendation be implemented:

Enhance battlefield threat assessment and response by supporting R&D in biotechnology that would improve methods for early detection, identification, and countermeasures to prevent or neutralize the adverse effects of chemical, toxin, or biological threats; counter nuclear and directed energy threats; and provide the means to reduce the risks from environmental hazards.

Medical Protection and Treatment During Combat

The first defense against the effects of hostile fire on the performance of soldiers is the continuous process of maintaining a healthy, physically fit, and psychologically resilient force, as described in Chapter 1. Once combat has begun, the process of medical prevention and treatment will continue with the aid of special devices and procedures that have been designed to enhance protection from, or to provide immediate treatment for, injuries resulting from battlefield hazards. These hazards include direct enemy action as well as dangers imposed by the environment.

As discussed in Chapter 2, the future battlefield will pose new types of antipersonnel threats that will be combined with the more familiar threats from explosive devices and projectiles. These new threats will include chemical and biological warfare agents delivered by artillery, bombs, rockets, or missiles and directed energy weapons such as lasers, high-powered microwaves, radio frequency waves, and other forms of nonionizing as well as ionizing radiation.

Combined with these new weapons is the addition of potential environmental and geographical extremes associated with contingency operations that require U.S. forces to deploy to remote areas of the world. The most likely environmental hazards are those of fighting in either the hot, dry, sandy climates of the Middle East and Africa or the hot and humid climates typical of southwestern Asia and Latin America. Fighting in these areas carries with it the added significant threat of infectious diseases, a special form of environmental hazard.

Finally, the future battlefield will challenge the soldier with extraordinary levels of psychological stress resulting from highly accurate and lethal weapons, silent and deadly chemical and biological agents, equally silent and dangerous directed energy devices, sustained operations, increased dispersion of units, and the uncertainty of contingency operations in remote areas. Development of medical protection and treatment for the soldier must keep pace with the development of these modern means of warfare.

One of the primary concerns (if not the first) of the medical department of the Army is specialized preventive measures on the future battlefield. These will include drugs and vaccines to protect soldiers against nuclear, chemical, and biological agents; physiological monitoring of body temperature, hydration, and alertness; specially designed ensembles for protection from projectiles, directed energy devices, and chemical and biological agents; and psychological aids, such as land navigation and local

communication devices that enhance the soldier's sense of security and provide information regarding available support.

Despite these aids to avoid injury, combat inevitably causes casualties. The second concern of the medical department involves the immediate assessment of injury at far-forward positions. Effective and immediate treatment on the battlefield at or near the site where injury occurs is crucial to saving lives. This treatment will become increasingly important to the rapid recovery of the wounded soldier and the prevention of permanent disability. In some instances, further evacuation may be avoided.

For the evacuated patient, the third concern centers on the field hospital system. The high-technology methods for medical diagnosis and treatment now common at major medical centers will be miniaturized and hardened for use in the medical field system.

The three foci of medical involvement on the battlefield are discussed in detail below. Ultimately, these three systems, working together, will greatly reduce personnel losses and hasten the recovery of those injured on the battlefield.

THE INTEGRATED SOLDIER PROTECTIVE SYSTEM

The development of an integrated soldier protective system will provide environmental and physiological monitoring, protective devices, ground navigation, local communication, and personal and medical data bases. Its use will revolutionize the following impact areas:

- *Command information.* The commander needs to know the health status and mental alertness of the troops to assess their effectiveness and to determine when rotations may be necessary.
- *Unit cohesion.* Future wars will require an even greater dispersion of individual soldiers. The ability to monitor the status of dispersed units or individuals will become a necessity. Knowledge of the relative locations of individual soldiers and their squads will make it possible to provide the individual soldier with information regarding military support available from fellow soldiers. Both the commander and the soldier need to communicate vital information, which will work to minimize the psychological impact of isolation and reduce combat stress.
- *Sustaining soldier capabilities.* Dispersion makes more imperative the individual soldier's ability to assess aspects of his or her condition and take corrective action. Examples of this would be drinking fluids to prevent dehydration, resting to prevent fatigue, limiting work loads to prevent heatstroke, and satisfying nutritional needs to maximize performance.

These impact areas can be assessed by monitoring a variety of physiological indicators: cardiovascular function, alertness and fatigue, dehydration, and physiological stress (i.e., temperature, immune response). After the monitoring data are transmitted back to a central facility, they must be processed and interpreted to provide the diagnostic indicators useful to the command structure. Appropriate displays will enable the medical command to monitor the status of the whole force. Tremendous advances in the transmission of images from computerized axial tomography, magnetic resonance imaging, positron emission tomography, etc., may, in fact, permit image transmission from anywhere in the world. This capability will reduce the need for personnel to interpret images on-site. However, operational security must be maintained throughout this communications process.

The Soldier Computer

Monitoring this diverse array of information will require an advanced soldier-borne electronics system. The future soldier may be equipped with an integrated electronic and computer subsystem capable of physiological and environmental monitoring, local and long-distance communications, and ground navigation. Referred to here as the *soldier computer*, it is a subsystem of the integrated soldier protective system. Such a computer system will require advances in the following technological areas: (1) noninvasive biosensors to detect physiological signs, (2) appropriate local processing in the individual soldier's microcomputer to present information to the soldier and reduce signal transmission demands on the central collection stations, (3) telemetry systems to communicate the information via satellite to central locations by using appropriate encryption techniques for operational security, and (4) extensive signal processing and integration techniques that use expert systems to provide analyses appropriate for return telemetry to the soldiers on the battlefield and for command decisions at headquarters.

Care must be taken to organize and analyze the information presented to the individual soldier and the command structure in ways that maximize the effectiveness of both entities. This decision-making input should be displayed to both the soldier and the command structure in a format that can be readily and accurately understood, yet it should be unintelligible to the enemy.

The soldier computer will initially serve to preserve performance and prevent injury by warning the soldier of needed corrective action—ingestion of fluids or special nutrients, application of medications, rest or sleep, or changes in location. Later, if the soldier is injured or incapacitated, the system will detect this change in status and provide, via remote and secure communication links, essential information for injury assessment, location, evacuation, and initial medical resuscitation.

Soldier Protection Subsystem

The prospect of exposure on the battlefield to a broad array of hazards—nuclear, biological, chemical, laser, directed energy, etc.—mandates dramatic improvements in the clothing and protective gear worn by the soldier. All such developments must, however, recognize that the foot soldier in particular cannot be so burdened with apparel and gear, no matter how impregnable, that it significantly interferes with his or her performance. Advances in ordered polymers are relevant in the development of nonburdening protective gear (see the chapter on advanced materials in the STAR Technology Forecast Assessments volume (NRC, 1993a)). Flammability and the consequent release of noxious agents become a central issue because weapons such as lasers concentrate energy beams on the soldier.

New materials will be developed for outerwear. Flame-retardant clothing will be improved, and lighter body armor, such as vests and helmets made of Kevlar®, will be more acceptable to the troops. Also, the quality and design of eye shields will be greatly improved to counter the anticipated use of more blast, high-energy-particle, and burn injuries in the future. Mechanical and electronic devices for blocking or canceling energy that affects the visual or auditory systems will be required to protect the soldier from a variety of high-energy sources (blast, laser, microwave, vibrational, and sound energies).

A combination of physical and biological protection against chemical and biological threats will continue to be of great importance. As the potential for the use of highly lethal, specially engineered chemical and biological weapons becomes greater, enhanced physical and biological protection against these threats becomes more vital. Physical protection that includes impregnable uniforms and protective masks is one approach, but, more advanced technological developments will require the counterapplication of even more advanced technology. This will include fabrics with selectively permeable membranes that exclude threat agents but allow the soldier to hear, see, move, breath, and perspire normally. A second, perhaps more effective, approach for some threat agents is the administration of physiologically protective drugs—either immunological or passive scavengers—that block or neutralize the adverse effects of entire classes of threat agents. This approach minimizes the performance impediments of protective clothing, but it will most likely be incomplete in view of the wide assortment of potential chemical and biological agents and the expanding means of production.

FAR-FORWARD CASUALTY ASSESSMENT, CARE, AND EVACUATION

The first and essential task when enemy action or an accident incapacitates a soldier on the battlefield is locating and medically evaluating the casualty. That task will become an integral aspect of the communications link to the soldier by the year 2020. By then a computer communicator the size of a wristwatch will link each soldier, via satellite radio, to field commanders and thereby enhance battlefield management (as described in the chapter on computer science, artificial intelligence, and robotics in the STAR Technology Forecast Assessments volume (NRC, 1993a)). For casualty location determination, the computer-communicator inputs will include, in addition to the soldier's voice channel, indicators of physiological condition (e.g., heart rate, respiration, body temperature, and an index of alertness). An interrogation system could periodically poll each soldier's status; if the system receives no verbal response, it could then request physiological data. If retrieval by medical personnel was indicated, interpretation of the satellite data would determine the geographical coordinate of the fallen soldier with the appropriate data being radioed to the corpsman or combat lifesaver (see discussion of the combat lifesaver below). The section on computer science, artificial intelligence, and robotics in the STAR Technology Forecast Assessments volume (NRC, 1993a) describes a legion of fist-sized, low-cost robots intercommunicating among themselves and with human commanders, serving both defensive and offensive roles. Such a network could also participate in the search for and location of casualties.

Impacts and Needs

Both the operational commander and the medical system benefit from immediate and accurate information regarding the location and extent of casualties. The benefits derived include:

- *Knowledge of status of the force.* The command structure must know the location and extent of casualties to maintain an effective fighting force.
- *Assistance in personnel planning.* The personnel system needs casualty information to schedule appropriate replacements.
- *Evacuation efficiency.* Knowledge of casualty location and identification is essential to the efficient deployment of retrieval resources.
- *Maximization of return to duty.* Early identification and prompt treatment of casualties can shorten the time until an injured soldier can return to duty, thereby conserving personnel.
- *Clearance of the battlefield.* It is important to clear casualties from the battlefield, so that the progress of military actions is not impeded.

Immediate Care

Immediate care of casualties requires precise information on the location and physiological status of wounded or otherwise incapacitated soldiers. This is essential if medical care is to be effective in minimizing losses; this same information is also critical for timely command decisions regarding the status of engaged forces for continued operations or the need for replacements or unit reconstitution.

The technology required to achieve these needs augments the previously described location and communications system. This technology must be an integral part of a total soldier-borne system that includes communications, navigation, weapons status and control, heads-up display, an informational database, environmental sensing, and physical protection.

Because the American public has become more medically astute, so have U.S. soldiers. The Army recently introduced the *combat lifesaver* concept. A combat lifesaver is selected in each squad of 10 soldiers, and, although this individual is not a medical soldier, he or she is given medical training beyond the knowledge of first aid expected from all soldiers for providing *buddy aid*. An example of a concept similar to the combat lifesaver was seen in the Falklands war, in which British soldiers carried their own intravenous fluids.

The importance of the combat lifesaver in providing immediate care will increase manyfold on the battlefield of the future. This individual will use advanced technological devices to administer lifesaving first aid measures. For example, the combat lifesaver will be able to control hemorrhage by inserting chemically impregnated, hemostatic, biodegradable bandages into a wound and to start an oxygen-carrying intravenous fluid to replace the oxygen-carrying capacity of the blood that has been shed. If the casualty's airway is blocked, the combat lifesaver will insert a cricothyroid cannula. In addition, the combat lifesaver will be able to notify medical personnel of the casualty's location and condition using an individual communications device. Other abilities will include applying lightweight folding splints to suspected fractures and dressing wounds.

In the resuscitation and evacuation of a far-forward combat casualty, the combat medic will provide follow-up care after the combat lifesaver. The role of the medic will be dramatically enhanced by future technology, just as the role of the emergency medical technician in the civilian sector has been and is being enhanced. The combat medic will utilize true resuscitation fluids, not just vascular volume expanders; new techniques of airway management; new methods of hemostasis; previously unavailable communication capabilities; and advanced evacuation platforms. The use of new technologies in the medical care system will noticeably reduce the possibility of a wounded soldier dying before reaching a medical treatment facility.

For the soldier who is incapacitated by chemical or biological agents, prompt detoxification can enable an early return to duty. The capability of

detoxifying biologically and chemically injured personnel and returning them to duty sooner than was previously possible would decrease the effectiveness of these agents, which could discourage their use by an adversary. Chemical and biological detoxification has been and will remain a priority of medical defense as long as the use of these agents persists. Monoclonal antibodies will be used for the detoxification of some agents. And genetic engineering and recombinant DNA techniques will be effective in identifying new substances that will enhance the soldier's defenses against other biological and chemical warfare agents.

Evacuation

Evacuation of battlefield casualties has become a part of the integrated treatment of patients rather than just being transportation. The progression of time and the conclusions drawn from experiences in past conflicts have created an ever-increasing recognition of the importance of rapid, timely, and medically attended evacuation as an integral part of the continuing treatment of a wounded, injured, or sick soldier. In the Civil War, long wagon trains traveling south from Gettysburg transported the unattended wounded, who usually deteriorated and died. Forward helicopter evacuation was introduced during the Korean war. Resuscitation and the use of rapid, medically equipped, and monitored evacuation vehicles at far-forward positions remain the two major areas that have significantly reduced the death rates of battlefield casualties.

The U.S. Army is the only military force in the world with helicopters dedicated to the evacuation of patients in forward positions of the combat zone. Dedicated evacuation platforms must remain under medical control for rapid evacuation, and there must be adequate medical equipment monitoring and adequate treatment of casualties by well-trained medical personnel. Evacuation must be phased into the plan of overall patient management, and resuscitation must be vigorous both prior to and during evacuation. Treatment of the patient should be continued during evacuation and must not be interrupted by it. The prompt clearing of casualties and evacuation from the battlefield permit the combat commander to pursue the battle without the hindrance of noneffective wounded and injured soldiers. Prompt clearing of casualties, vigorous resuscitation, and rapid evacuation to a forward medical facility prevent deterioration of patients and thus decrease morbidity and mortality.

Monitoring of the patient for any deterioration during evacuation is mandatory. One of the recurring lessons of the Vietnam war was that rapid evacuation is of the greatest value when it is integrated with vigorous resuscitation prior to and during evacuation. Prompt evacuation of casualties demonstrates to the wounded soldier that the Army is concerned about his or

her survival, and this has a major and positive impact on troop morale. The means of evacuation must remain under medical control, with the designated receiving hospital being determined by medical controllers. All personnel aboard any means of evacuation must be medically trained. Advances in diagnostics, monitoring, robotics, and propulsion will revolutionize evacuations.

New technologies will be used to develop encapsulated mobile robotic platforms that will provide environmental protection and physiological monitoring for evacuation of the wounded. These platforms will be integrated into the location monitoring and communications system previously described. The technologies that will enhance the platform will be advanced materials and new power sources. The casualties will be *pressure suited* or placed in protective cocoons, if necessary, to maintain blood pressure while aboard the platform. Operational security will be maintained by encryption, stealth, or medical designation (as mandated by the Geneva Convention); the choice will be determined by command decision.

The increasing height of U.S. soldiers requires abandonment of the fixed litter length of the past 50 years. Telescopic litters will be required that will fit into existing vehicles but also be of adequate length to support taller soldiers. New materials for litters will provide a soil-resistant surface made of comfortable, durable, and easy-to-clean cloth materials. Planners should develop equipment designs that are compatible with other system applications and implementations. They must also recognize that transportation of the injured individual may revert to the use of the litter and ground ambulance at times during a conflict.

In the event of chemical or biological contamination of an injured soldier, decontamination will be required prior to forward treatment and evacuation. In the future this may be accomplished by using biological decontaminating agents that are nonhazardous to the soldier and that permit his or her entry into a protective shelter without the need for removing the protective ensemble and without presenting a hazard to the personnel in the shelter. Biodegradable agents derived through biochemical engineering techniques can be sprayed over the soldier, rapidly denaturing any chemical agents that may contaminate the uniform or exposed skin. Degradation of chemical agents that may have been imbedded in a wound may be required before the casualty can enter a protective shelter, and the same biodegradable agent will be used to irrigate the wound.

FIELD MEDICAL SYSTEM

This section acknowledges a projected basic trend that future wars will be highly mobile, will probably be conducted on a smaller scale, and will be of shorter duration than the Vietnam or Korean wars, or World Wars I and

II. Because modern armaments will have an ever-increasing potential to produce wounds, the number of casualties in any given area may exceed the capacity of the military medical units. Thus, local civilian units may need to assist in the care of casualties.

The Army now possesses rapidly mobile hospitals for use in combat zones, and considerations indicate that their use will continue. Unfortunately, the deployable medical hospitals require a fleet of heavy trucks for transportation on reasonably good surfaces and a construction battalion to make them operational. The additional logistics of supply, maintenance, and manpower suggest that these units are too large and complex to serve the needs of future hospitals deployed at forward positions. Furthermore, it is unlikely that the air superiority enjoyed in recent conflicts, which made helicopter evacuation of the wounded and placement of resuscitative hospitals in close proximity to the front feasible, can always be ensured.

There are several assumptions regarding medical care in the field that should be considered. Medical manpower at the most forward position will continue to be one corpsman per platoon and one physician per combat battalion. The aid station at the most forward position will be manned by medical personnel capable of implementing advanced trauma management and managing life-threatening injuries. Their responsibilities will include maintaining an adequate airway, controlling hemorrhage, reexpanding vascular volume, stabilizing fractures, and protecting wounds. Their goals are to triage, stabilize, and prepare for transport wounded individuals who cannot be returned to the front line.

Strict adherence to the traditional concept that triage of casualties for care should be performed by the most experienced physician is open for debate. The initial triage will probably be done at the forward aid station. Dentists or nurses may provide triage in forward hospitals. The number-one priority for triage at the initial aid station is to return as many soldiers to duty as possible. Complex medical care is a second priority. The priorities for medical care are to preserve life and bodily function.

Increasingly, medical care is most likely to be provided in a sequential manner at different sites rather than in one location. Resuscitation and stabilization will generally occur at the forward position and increasingly definitive treatment at the rear position.

The small, highly mobile hospital will remain the first level of hospital care. Surgeons require a hospital in order to provide the range of resuscitative surgeries for which they are uniquely qualified. Their skills will be wasted if they are assigned to aid stations at more forward positions. Experience indicates that tents will serve adequately for shelter and function at forward surgical units. The forward surgical hospital will be a mobile facility that will use a lightweight, rapidly erectable shelter system. It should be located as close to combat action as the tactical situation permits. In addition, transport,

communications, and supplies must be considered. Ideally, the hospital will be within a few miles of the front to provide prompt surgical resuscitation.

The primary mission of the forward surgical hospital is to surgically stabilize the patient for more extensive care at a subsequent hospital farther to the rear. Thus the surgeries performed in this forward hospital will include such procedures as the control of hemorrhage and repair of major vascular injuries; diversion, repair, or removal of injured bowel; stabilization of major fractures; and support of respiratory, cardiac, and other vital functions.

In anticipation of more injuries from lasers and other directed energy weapons, it may also be necessary to have an ophthalmologist assigned to the forward surgical hospital. An ophthalmologist could function very effectively in a forward hospital with miniaturized ophthalmologic equipment.

Less urgent procedures or more time-consuming ones will be done in hospitals located to the rear of the primary hospital. These procedures include, for example, dental implants, use of artificial skin, use of prostheses, organ transplants, implantation of limbs, and nerve surgery. Brain surgery will be less extensive than it was in the past because extensive debridement to remove foreign bodies is no longer considered optimal therapy.

Impact and Needs

An improved field medical system will have benefits for both the operational commander and the medical system. In terms of command, unit strength and tactical flexibility will be enhanced by reduced numbers of personnel being killed in action and dying of wounds as well as by the return to duty of sick, injured, and wounded personnel more rapidly and in greater number.

Triage and medical control systems also will be more efficient. Reductions in patient treatment time will decrease the demand for medical personnel, medical facilities, and transoceanic support. Among the contributing improvements will be on-site production of intravenous fluids, oxygen, and vaccines; more rapid patient assessment; and faster information flow among medical units in the field to provide data on occupancy and the availability of medical resources.

Technological Approaches

The fluidity and rapidity of military action and the dispersed character of the future battlefield will influence the kind and location of facilities for medical treatment. The emphasis will be on compact, lightweight, highly mobile medical facilities for diagnosis and forward medical treatment and on extensive digital signal processing and computer utilization, including medical

data bases. Among the needs of the field medical system are field medical devices; new battle dressings; filter absorption systems; on-site oxygen production or conversion; improved venous access devices; improved peripheral perfusion and ischemia monitoring; and self-calibrating in vivo blood gas, pH, and electrolyte monitors.

The *field medical devices* that are needed are medical data bases that characterize the individual soldier's medical history coupled to the soldier/battlefield monitoring system.

Already available for use are *new battle dressings*. These are in the form of self-contained gel dressings for application to burned skin. They provide protection from further damage to the skin as well as relief from pain. The dressings are designed so that they expand with moisture derived from the air when their packet is opened.

Both *filter absorption systems* and *on-site oxygen production or conversion* will be important to the field medical system. The absorption systems will be used for on-site production of sterile fluids, including intravenous fluid. While on-site oxygen production or conversion is not yet possible, it is anticipated that in the future enhanced technological developments will provide this capability.

To reduce the complications of infection, phlebitis, or thrombosis, *improved venous access devices* will be used. The results of initial trials of one such device have been promising and without adverse effects for test periods up to two weeks. Problems that need to be resolved relate to the rigidity of a metal needle and electroplating with the least irritating metal surface.

Improved peripheral perfusion and ischemia monitoring will be used to enhance shock trauma management. Most investigators and experienced clinicians accept a definition of shock as a persistent state of poor peripheral perfusion. To date, evaluations of the severity of shock can be made only on a clinical basis, supplemented with indirect laboratory measurements. Both clinical care and research would benefit from a more direct assessment of peripheral perfusion. A novel integrated hybrid thermistorpolarographic sensor that combines measurements of temperature (as an index of tissue perfusion) and of oxygen tension (as an index of tissue ischemia) may soon be available for clinical trial. The thermal probe is already available and incorporating a gold-plated, flow-insensitive oxygen sensor with it may allow measurement of oxygen tension to be correlated with perfusion. In contrast to the current state of the art (i.e., microbeads used to assess perfusion), this probe would allow on-line readings to be repeated indefinitely. The probe will be introduced with a needle or catheter. The major problem to be resolved is the suitability of the gold-oxygen electrode for rapid measurements during the state of reduced perfusion that develops during hypovolemic shock.

Another important need for the field medical system is for *self-calibrating in vivo blood gas, pH, and electrolyte monitors*. A limitation of current instruments for continuous monitoring of blood gases and pH is their

requirement for frequent and recurrent calibration. Also, the invasive instruments require frequent sampling of blood, and the noninvasive instruments are less reliable and depend on cutaneous circulation. These disadvantages will be circumvented by the development of a membrane for a disposable intraarterial device that will continuously monitor arterial oxygen pressure, arterial carbon dioxide partial pressure, pH, and electrolytes and will require no laboratory calibration or removal of blood. The supporting sensor technology for gases and electrolytes has been established. To meet the specifications for the blood gas, pH, and electrolyte monitor, a desired membrane must have ion and gas diffusibility and resistance to protein fouling and clotting.

Biological Products

Bandaging material that is impregnated with *new hemostatic agents* and that can be inserted into a wound would control most bleeding. The only exception would be hemorrhage from a major vessel, which might require a tourniquet depending on the location of the hemorrhage. Frequently, troublesome bleeding is not from a major vessel but is continuous significant hemorrhaging from many smaller vessels. Hemostatic wound dressings combined with small-volume, stable, concentrated oxygen-carrying fluid would diminish shock as a problem in combat casualties.

Monoclonal targeted antibodies can be used for topical therapy of wound infections and burns.

Artificial skin and bone can be used as tissue substitutes to facilitate wound healing, burn control, fracture stabilization, and prevention of permanent disabilities. A combination of synthetics with biological materials, which replicates the role of the epidermis, makes up membranes that are now in clinical trial. They will certainly improve throughout the 1990s. Reconstitution of the dermis, based on seeding cells from the patient's skin into the membrane, is currently at the research stage. It appears to replicate normal tissue and significantly reduces contractures. These same techniques offer promise for forming epineurial sheaths to guide axonal growth in peripheral nerves and for use in blood vessel prostheses. An alternative research approach involves replication of the patient's own skin cells on the massive scale necessary to produce adequate coverage.

Artificial blood vessels—new, smaller-vessel prostheses—continue to provide a developmental challenge. Conventional Dacron grafts maintain long-term patency in large-caliber vessels but are not usable in small ones. A new prosthetic graft uses an integrally textured polyurethane fibril surface to promote the disposition of pseudointema from blood flowing over its surface—similar to the effect of Dacron and expanded Teflon. It differs from other prosthetics in that it adjusts the compliance to match that of a

comparable small-sized vessel and uses a textured surface on the exterior of the graft. The external surface is expected to promote attachment of tissue that will maintain the compliance of the graft within a physiological range after healing of the perigraft tissues. The integrated construction of the prostheses should prevent the complication of fibril shredding that is characteristic of adhesively bonded fibril surface systems. Because the bulk mechanical properties of the graft are principally determined by the solid nonporous substrate, the desired graft compliance should be achievable by simply adjusting the substrate thickness. The primary goal of this work is to reduce the development of intimal hyperplasia at the site of graft anastomosis, which would compromise the lumen of the small vessel. The hypothesis is that to prevent undesirable hyperplasia a graft must remain compliant following healing of the perigraft tissues.

Cultured skin grafts or cultured epidermis for the treatment of massive burn wounds are still a topic of controversy, even though the technique for covering burn wounds with cultured cells has been available since 1984. A recent study, however, demonstrated a significant reduction in both morbidity and mortality in patients suffering from burns on 40 percent or more of their body who were treated with cultured keratinocytes. Discounting disagreements over the statistical validity of the study, questions remain about the durability of this cultured graft, which lacks rete pegs for adhering to underlying tissues, and about the tendency of thin grafts to contract. And although donor skin can be expanded 1,000-fold by culture techniques, protection of the injured areas while the cell cultures are growing is an important problem.

Research on the production of *endotoxin vaccines* for the treatment of shock supports the original work of George Crile, Sr., Joseph Aub, and Jacob Fine in the early twentieth century. They suggested that some type of toxin (or toxins) develops during prolonged severe hypoperfusion of tissues during shock. Recent evidence shows that the toxin in the gut stems from the loss of the barrier function in the hypoperfused area. This permits the migration of toxins, or perhaps whole bacteria, across the gut wall and into the circulation. Hypoperfusion also damages the reticuloendothelial system and diminishes its protective barrier. The entrance of a toxin or bacteria into the circulation may be the primary cause of the pulmonary complications or multiorgan system failure responsible for most deaths after prolonged shock. Prevention of these life-threatening consequences of shock will require rapid and adequate restoration of circulatory volume, the use of broad-spectrum antibiotics, and some type of vaccine to neutralize the effects of the liberated toxin. Nutrition to protect the liver and the gut barrier function also are vital areas to be examined.

Pharmaceutical Developments

Various pharmaceutical developments are needed to enhance the field medical system of the future.

- *Drugs* are needed to assist in more rapid recovery from acute stress reactions.
- *Pharmaceutical agents and methods* for induction of hibernation in casualties are needed to suspend deterioration while awaiting definitive diagnosis and treatment.
- *Means to protect and detoxify biological and chemical agents* are needed.
- *Microencapsulated antibiotics* with the capability of providing sustained, high local levels and minimal systemic levels of antibiotics (implanted at the time of surgery) are needed.

MEDICAL CIVIC ACTION

In addition to its role as medical provider for military personnel, the Army medical corps is sometimes called on to provide civic medical assistance in areas under Army control. The problem of treating civilian casualties has proven to be an overwhelming burden in all conflicts. This dilemma surfaced most recently in the Persian Gulf war and in the Panama operation. In such cases, civilian casualties may not be able to travel to their local medical facilities because of the disruption caused by hostilities. Experience has repeatedly shown that civilian casualties arrive at the closest military medical facility for treatment. Yet despite the extra burden these casualties place on medical personnel, equipment, and supplies, they are not part of the present planning and management process. Medical management of civilians and enemy prisoners of war will remain a serious problem for the Army medical department.

It is difficult, if not impossible, to turn wounded, injured, or sick civilians away without treatment. However, very little, if any, effort has been expended on planning to rebuild or restore the responsibility or mission of local medical facilities. If, after treating military personnel, they have the time and resources, military medical personnel should assist local medical personnel in treating civilian casualties. Advanced planning should be implemented to avoid problems that cause logistical shortages and burdens on military medical personnel. The medical leadership in the military also needs to provide for the continued functioning of existing indigenous medical facilities and to facilitate the return of local medical personnel to staff these facilities.

Civic medical action represents an operational problem rather than one that is solved by the insertion of new technologies. There are several approaches that should be considered. One is to designate specific Army field hospitals for the treatment of civilians or enemy prisoners of war. Another is to delegate the missions to hospitals that serve a particular geographic area. Specific logistical support that is not usually needed in the medical equipment set for combat operations is required for civic ones and must be taken into account.

CONCLUSIONS AND RECOMMENDATIONS

The battlefield of the future will require improved methods of medical prevention and treatment using special devices and procedures designed to provide enhanced protection from, and immediate treatment for, injuries resulting from direct enemy action and environmental threats. The panel therefore encourages the Army to implement the following measure:

Accelerate and support R&D on the integrated soldier protective system; on field medical systems by emphasizing mobility and resuscitation at far-forward positions; and on novel replacements, such as skin grafts, artificial blood, and fluid substitutes.

Required Supporting Capabilities

The enhancements to the U.S. Army's medical capabilities discussed in the previous chapters will require focused programs in continuing medical education and the development of a variety of material products and methods. In assessing current and anticipated technologies, it is logical to expect that some of the educational programs and new products will evolve as spinoffs from advances in civilian medical centers. A significant number of technologies, however, will require collaborative or total development by the Army in order to meet the specific needs of the military. For example, it is reasonable to expect that drugs for the prevention and treatment of injuries from nuclear, chemical, and biological warfare agents will be developed solely by the Army. Vaccines against infectious diseases, telemetry, physiological monitoring systems, psychological support devices, improved nutritional support systems, new agents to replace blood volume, and improved medical care and educational programs are examples of advances that will evolve in conjunction with civilian programs. The rapid and ongoing changes in medical diagnostic and care equipment will require considerable adaptation and hardening for use on the battlefield.

To assist with the needs of the military and to take advantage of the advances made in civilian laboratories and hospitals, the Army must maintain and enhance its capabilities to support education and research programs. To achieve this objective, the Army should develop and support the following:

- programs for the recruitment, development, and retention of biomedical scientists for in-house medical research and
- specialized civilian/military centers for clinical care, education, and research relevant to the primary mission of military medicine.

RECRUITMENT, DEVELOPMENT, AND RETENTION OF MEDICAL RESEARCH PERSONNEL

Any research institution must have an active program of recruitment and retention of professional and technical staff. In the case of the research and development (R&D) institutions of the Army, this program must apply to both military and civilian personnel. These are the individuals who are needed to maintain the science and technology watch and engage in the development of relevant technologies. Although panels of consultants can be of assistance in these efforts, the guiding thrust must come from Army

medical R&D personnel who are trained scientists and who are fully aware of the medical and strategic missions of the Army.

Successful R&D organizations recruit the bulk of their professional talent soon after a professional degree (M.D. or Ph.D.), including postdoctoral research and subspecialty training, is completed. From time to time, it is necessary to recruit more senior, specialized scientists to assist in the development of a research program as new scientific breakthroughs occur. Regardless of the recruitment method, there must be an innovative and creative plan for retaining the R&D personnel with the most valuable skills.

In the decades ahead, recruitment of young talent will become more and more competitive as the demand increases for civilian R&D in both the private and public sectors. A number of studies have projected a short supply of scientists with Ph.D. and M.D. degrees by the year 2000. The Army must therefore devise recruitment strategies to compete for talent. In light of high tuition costs for a medical education, by using the idea of financial assistance, it should be possible to develop innovative programs that will attract more medical students and encourage them to pursue careers in biomedical research. New initiatives include an Army-supported M.D. and Ph.D. program and an Army-supported postdoctoral training program. Such training should be in the very best biomedical research laboratories and not limited to Army institutions.

Retention of scientific talent poses another set of problems that will require new thinking about personnel management. It may be desirable, for example, to create a new career path for a category of R&D officers. Such a path would have the potential for flag rank on the basis of research achievement, as is the case for officers in the U.S. Public Health Service. In addition, Army financial compensation for scientific talent must be in a range that is competitive with that of the academic community.

The retention of civilian scientists involved in Army medical R&D brings up completely different issues. The Army must examine the current career structure and devise new policies that will encourage the retention of the most highly qualified individuals. The Federal Senior Scientific Service, as used at the National Institutes of Health, or some modification of it, would be one way to provide adequate compensation for scientists with special talents.

TRAUMA, TRAINING, AND TREATMENT CENTERS

A specialized center for the study and treatment of trauma, which would combine clinical care, physician education, and research, is needed if the Army is to make advances in treatment and decrease the number of mortalities caused by injury (Figure 4-1). Such a center should provide an opportunity for the development of innovative surgical procedures and new



FIGURE 4-1 Trauma centers: a cooperative civilian and military effort. (Courtesy of the Maryland Institute for Emergency Medical Services Systems, Baltimore, Maryland.)

pharmacological interventions that enhance a person's ability to recover from trauma.

These types of advances will require fundamental and clinical research on the altered physiology of patients with trauma and on the mechanisms of tissue, nerve, bone, and vascular regeneration. New methods must be developed to enhance recovery processes. Such developments are unlikely to come from the civilian sector. Research on trauma and clinical research in trauma surgery have not been a priority of the National Institutes of Health or other health funding agencies. Thus, there is a compelling need for military physicians to be skilled in the field of trauma. Yet because (prior to Desert Storm) there has been no broad military confrontation since the end of the war in Vietnam, very few active-duty physicians have had extensive experience in trauma treatment. On-the-job training after hostilities commence is not an

acceptable component of planning. For all of these reasons, the Army must develop a plan for creating one or more centers that will enhance patient care, training, and research on trauma.

The value of trauma centers in providing optimal care for injured patients has almost become axiomatic. Many studies indicate that despite the presence of qualified general surgeons in hospitals that lack a medical staff focused on and specially trained in trauma management and care, there are more management errors and a significantly higher rate of preventable deaths. Fewer malpractice claims from the care of injured patients originate from trauma centers. Furthermore, costly diagnostic and therapeutic equipment—available in trauma centers—is becoming a prerequisite for the most efficient and effective care of injuries. Yet escalating nonreimbursable costs plus management difficulties in coordinating hospital and prehospital care and allocating scarce resources have become major impediments to the desired development of trauma centers throughout the United States.

The needs of both the civilian hospitals and the Army would be resolved by the development of trauma centers in which the Army has a significant role. By supplying personnel, physicians, nurses, and corpsmen in need of the in-depth and long-term experience available at a trauma center, the Army would contribute to the reduction of significant personnel costs to the hospital.

An additional advantage for the military stemming from the development of trauma centers would be the opportunity to conduct clinical and applied basic research on current and projected problems regarding the care of injured soldiers. Involvement in a trauma center would be an excellent illustration to the public of an important role for the military in peacetime. The epidemic of violence involving guns and knives among civilians in most U.S. large cities could be a resource to train and maintain a group of military physicians, nurses, and corpsmen thoroughly experienced in the responsibilities they must assume during armed conflicts in the next 30 years.

CONTINUING REQUIREMENT FOR ARMY MEDICAL R&D

Maintaining the Technology Watch

There is general agreement that in the past 10 to 15 years fundamental knowledge has accumulated much more rapidly in biology and medicine than it has in many other sciences. This is primarily due to the use of biochemistry and the physical sciences to study biological processes. Noteworthy advances have been made in many areas, including the following:

- the chemical structure of the gene and gene action;
- differential gene expression;
- cellular structure and cell regulation;
- cell membrane function and cell signals transmitted by receptors and channels;
- specificity and regulation of the immune response; and
- nerve cell communication and the neurobiology of learning, perception, motor control, and cognition.

These developments in biology and their application to medicine have required the evolution and use of complex technical equipment, including computers. Modern biochemistry, for example, rests on the development of such instruments as the amino acid sequencer and the nucleic acid synthesizer. These and most other such instruments require on-line computer technology.

Because of the pressing need to discover solutions to major health problems, the emphasis in biological research has been on human biology and closely relevant areas such as microbiology. This focus is now shifting to areas of biology that have been less intensively studied but that can be applied to the chemical and physical sciences. For example, advances in molecular and cell biology are now diligently applied to fundamental research in botany and entomology. It is likely that new biological principles, which will be applicable to medical research, will emerge from this research. The following are the type of relevant questions that might come up: Do plants possess antiviral substances that would be effective in treating human viral infections? Do they possess substances that promote tissue regeneration after injury and that would be applicable to the restoration of tissue damage caused by injuries in humans? Will modern studies in entomology lead to new ways of controlling the multiplication of insects that transmit tropical diseases to humans?

The Army must pay close attention to advances in science and technology in order to select those that are most likely to yield new methods to treat diseases and injuries. Only in this way will the Army be able to continue, during the next century, with the remarkable strides in military medicine that have been made with each successive war since the Civil War. For example, gene therapy has become a new paradigm in medical treatment. It is likely that this technology will prove to be a major influence on the field of medicine in the twenty-first century in the same way that antibiotics have impacted the field in the latter part of this century.

There is another aspect to the science and technology watch that deserves comment here: the emergence of new diseases and the eclipse of those that were once very common. The Army must be alert to such changes and develop strategies to meet new threats. Streptococcal pharyngitis and rheumatic fever were epidemic in military training camps during World War II. Now these diseases are no longer a problem. In the past decade, however, acquired immune deficiency syndrome (AIDS) has spread from Central Africa

to North America and other parts of the world, and Lyme disease is epidemic in many of the forested regions of the world. Because emerging microbes will continue to be a threat in the future, the Army must maintain a science and technology watch to recognize these new dangers and devise solutions, especially when the hazard is a major threat to the health of individuals in the military, whether on duty in the United States or deployed elsewhere.

Worldwide Technology Watch

This commentary would be incomplete without mention of new developments that will occur overseas, particularly in an increasingly integrated Europe, Japan, and the Pacific rim countries. During the past 25 years, the bulk of all worldwide R&D has occurred in the United States. This will shift in the future, with a greater part of this research being conducted abroad. For this reason, the Army must be especially alert to new scientific advances throughout the world, not just to those that stem from domestic R&D.

Overseas Laboratories: Military Medical Research

Many of the strategies for new technological development in support of medical care depend on real-time, hands-on assessment in human populations exposed to known risks. Laboratory evaluation and animal testing are clearly also important preliminary avenues for the development of new medical therapies. Often, however, the populations at risk of exposure to unusual diseases exist only in other countries. The military already has an extensive and effective international group of on-site laboratories. In critical areas of the world, these need to be developed, expanded, supported, and oriented toward the development of the new strategic technologies that will be developing over the next 30 years. Special areas of responsibility include:

- vaccine development;
- new antimicrobial therapy;
- new antiviral therapy;
- new antiparasitic disease therapy;
- maintenance of knowledge of changing characteristics of diseases to ensure that current therapies are adequate;
- an understanding of the capabilities of potential allies to deal with on-site medical problems;
- continuous on-site surveillance of episodic diseases;
- continued evaluation of vector changes and evaluation of currently available control systems;

- evaluation of local diseases and potential stresses to new troops in any given area (e.g., filariasis in Central Africa);
- maintenance of contacts with ministries of health to secure available data on various continuous or episodic disease risks within a country; and
- assessment of new rapid diagnostic procedures in a hands-on environment.

Most crucial to the maintenance of overseas facilities are factors of adequate siting and critical mass of personnel.

So that they are representative of the great variability of diseases in each area, it is imperative that the sites for overseas laboratories be maintained. It is also important that these laboratories be located where political and administrative interactions with local ministers of health provide sufficient support to ensure the continued operation of laboratory systems. Currently, the military has two major laboratories in southeastern Asia (Djakarta, Indonesia, and Bangkok, Thailand); two laboratories in Africa (Nairobi, Kenya, and Cairo, Egypt); and two in South America (Peru and Brazil). Past experience has shown that changes in the political status of countries can sometimes lead to ineffective, but continued, operation of laboratories. Therefore, having the presence of two laboratories in each continental area seems the bare minimum necessary to provide for an on-site presence to fulfill the responsibilities of overseas laboratories.

The value of such overseas laboratories has been supported in terms of the technological developments and new medical programs that might become available over the next 30 years. The laboratories also provide personnel with resources and facilities that can be mobilized quickly to respond to issues arising in areas of military conflict. A good example is the development of an on-site laboratory to evaluate the risks of exposure of personnel in Saudi Arabia. An extremely rapid response was provided by the Naval Medical Research Unit 3 (NAMRU3) in Cairo to develop a program that provided necessary information to local operations personnel in the field to ensure optimal treatment oriented to the specific problems of the disease patterns in this area of the Middle East.

CONCLUSIONS AND RECOMMENDATIONS

To enhance their required supporting capabilities, the Army will have to take full advantage of advances made in civilian and commercial sectors (e.g., hospitals, universities, and laboratories). It will have to monitor programs and research in these sectors, collaborate and integrate developments, and in some cases adapt and harden these developments for use on the battlefield. The panel suggests that the Army maintain and

enhance its required supporting capabilities by strengthening its medical R&D infrastructure through the following actions:

1. *Emphasize the necessity for U.S. Army medical R&D and for recruitment and retention of medical research personnel.*
2. *Develop trauma centers for research, treatment, and patient care.*
3. *Develop a center for biobehavioral research for the prevention and treatment of psychiatric illnesses and conditions; the study of sleep deprivation, stress, and behavior modification; and training and cognition in war and peacetime.*
4. *Maintain U.S. medical R&D in overseas laboratories to detect the early occurrence of microbial diseases and chemical, toxin, or biological weapon threats.*
5. *Develop and strengthen collaborative relationships among universities, industry, and the Army in laboratory and clinical research, thereby making available new technologies for Army medical research with emphasis on the treatment of trauma, infectious disease, neurobehavioral science, and molecular biology.*

Future Prospects and Advances in Science and Technology

BIOLOGICAL AND BIOTECHNOLOGICAL ADVANCES¹

The characteristic of the new biology on which much future medical research will be based is that biology has become an interactive science in which the traditional disciplines, such as physiology, biochemistry, and genetics, are being combined to address the needs of modern science. This transformation, however, has not been the only reason for the incredible strides that have been made. Also important has been the development of powerful instruments and techniques, including the production of monoclonal antibodies, recombinant deoxyribonucleic acid (DNA) techniques, and microchemical techniques such as those used to synthesize or sequence macromolecular proteins as well as nucleic acids. The most important advances have been in computer applications and data collection and analysis. Certainly, future development of improved techniques and instrumentation for biology and medicine will require that the barriers between biology, chemistry, physics, and engineering be torn down, generating a new cadre of biological engineers.

Future opportunities for better medical care for Army personnel can be identified from current advances in several different areas of biology.

Structural Biology

All biological processes ultimately depend on the events that occur between macromolecules that perform specific functions. These macromolecules include proteins (and peptides), nucleic acids, carbohydrates, lipids, and complexes. Research aims at predicting the relationship of structure to function and the behavior of these macromolecules from their chemical formulas. This requires three-dimensional structure analysis at the atomic level by x-ray diffraction techniques. Such methods are used to determine the structures of nucleic acids, antibodies, and enzymes, as well as the much more complex structures of entities such as virus particles. It is expected that, with the extension of x-ray analytical methods, the structures of even larger complex molecules and larger molecular assemblies will be determined in the next few decades.

¹Synopsis from NRC, 1989.

An impediment to understanding how proteins function has been the lack of knowledge about their three-dimensional structure. A predictive account of how folding occurs to create the three-dimensional structure from a long molecular chain will be a major advance in the next 10 years.

It is now possible to design and construct new macromolecules through the use of recombinant DNA technology and chemical synthesis methods. These macromolecules will provide new pharmaceutical agents and experimental models for protein function. Indeed, the advanced techniques are already being used to devise new antiviral drugs for the treatment of acquired immune deficiency syndrome (AIDS).

Genes and Cells

To a surprising degree, all cells are similar in design and function, whether they are the cells of humans and higher plants (eucaryotes) or those of simple, single-celled organisms (procaryotes). The entire developmental process, from the fertilized egg to a complex organism containing as many as 1 billion trillion cells, is regulated by myriad interactions within and among individual cells, all of which are under genetic control. The cycle of activity resulting in growth and development can go awry in some cases, leading to abnormal states characterized by disease in humans, animals, and plants.

The ways in which cellular components interact to propagate, store, and express an organism's genetic information are steadily becoming more clear. Issues that have concerned biologists for decades, such as the mechanisms of DNA replication, recombination repair, and gene expression, are being elucidated at a level of detail that was previously hard to imagine.

Another area of cell biology is the molecular basis for the complex interactive matrix of chemical reactions and transport systems inside the cell. Protein synthesis occurs in the cytoplasm and is followed by transporation of the protein to the correct intracellular location. This process involves targeting, sorting, and the regulation of protein synthesis. The mitochondrion, a cellular organelle probably derived from ancient symbiotic bacteria, produces most of the adenosine triphosphate (ATP) for the cell. In turn, ATP is the direct source of most of the energy required for cellular functions.

An understanding of the basis of cellular motility is also central to understanding cells. Three types of protein polymers contribute to the cytoskeleton and interact with force-producing enzymes to cause the motion of cells and organelles. Work in this area has already contributed many new insights into the molecular basis of cell organization and dynamics, but much remains to be learned.

Another area of cell research with special relevance to medicine focuses on cell-to-cell communication mechanisms. Growth factors, hormones, and their receptors, coupled with signal transduction mechanisms and

secondary messenger activity within the cell, create a communications network that allows the cell to react to its surrounding environment. Many disease conditions, including cancer and certain types of mental illness, are believed to result directly from abnormal cellular regulation. Therefore, research on cellular structure, function, and communication can provide a deeper understanding of human disease and may possibly result in improved treatments or even cures.

The impact of molecular biology on understanding cell regulation cannot be overemphasized. Until 10 years ago, scientists thought there were single channels for the passage of sodium, potassium, and calcium ions through the cell membrane; gene cloning has disclosed at least 20 separate channels for these three ions. Seventy-five years of physiological and biochemical research showed that there were two receptors for acetylcholine, a major chemical mediator of the brain and nerves; in the past decade, molecular biology has revealed at least 12 receptors. Since each receptor is a potential target for new drugs, there is great hope for future therapy.

Developmental Biology: Understanding Growth, Development, and Aging

Biology is now poised for an assault on one of the most intractable problems in biology and medicine, one that has eluded the best efforts. How does an organism develop from an embryo into its adult form? The fertilized egg differentiates as it divides and multiplies into the specialized and distinctive cells of the brain, heart, liver, lungs, bones, sex organs, and so on. This process of *cell differentiation* can now be understood primarily as *differential gene expression*. Molecular biology is beginning to provide an understanding of how gene expression is controlled during development.

How is the cell number controlled in different tissues of the adult? What genetic and physiological mechanisms determine the life span of cells and organisms? The questions are numerous, but the possibilities for biology and medicine seem endless.

Developmental biology will surely bring an entirely new understanding of disease processes that arise out of disturbances in developmental mechanisms. Indeed, developmental biology may help scientists discover the secrets of the aging process and perhaps the clock that keeps biological time. Perhaps the mechanisms that control life span can be altered to diminish the occurrence of the diseases of aging that can subtract up to 40 years of life.

Organ System Biology

Since the early studies of the French physiologist Claude Bernard (1813-1878), it has been known that there are intricate relationships among the organ systems of the body: between the nervous system and the endocrine system, between the circulatory system and the genito-urinary system, and so on. New methods to examine these relationships have emerged from cellular and molecular biology. Indeed, research on the organ system as it relates to integrative biology is an exciting new frontier. The complex organ system, so painstakingly dismantled, as if it were an intricate Swiss watch, must now be reassembled according to the blueprints of modern biology.

Future knowledge derived from organ system physiology will have a profound impact on the practice of medicine and is highly relevant to the Army. Developments will include new anesthetics and analgesics, new cell targets (receptors) for more efficient drug delivery, new drugs to treat shock and control hemorrhage, and new drugs to reverse paralytic ileus and kidney shutdown after abdominal injury and extensive surgery.

It is beyond the scope of this review to consider these matters in detail. One recent discovery, however, illustrates the rapid advances occurring in organ system biology. It concerns the detection of a hormone produced in the heart that is transplanted by the blood to the kidney, where it has profound effects on kidney function. Quite unexpectedly, a previously undetected peptide hormone, now termed atriopeptin, was discovered. This substance was detected as a product of the cardiac atrial muscle wall. It is a cardiac hormone intimately involved in fluid, electrolyte, and blood pressure homeostasis. Basal levels of circulating atriopeptin can be increased by atrial stretch caused by, for example, blood volume expansion. A promising clinical target for research on atriopeptin therapy is renal failure. This research will be applicable to the stabilization of severely wounded patients as well as surgical patients who develop shock and kidney shutdown.

The Immune System and Infectious Diseases

The immune system has developed in all vertebrates to deal with the challenge presented by pathogenic microbes, malignant cells, and foreign macromolecules (allergic substances). Perhaps the most remarkable aspect of the immune system is the specificity of antibodies and T-cell receptors for antigens from microbes and other environmental sources with which they must cope. Recent genetic studies have revealed the complicated mechanism of genetic rearrangement that is partly responsible for the specificity of antibodies and receptor molecules. These studies have also identified the mechanism for the generation of this large repertoire of binding sites.

Although much has been learned, the processes through which the individual immunoglobulin and T-cell receptor genes are activated and through which rearrangements are controlled are still undergoing intense investigation. An important area of research is the identification of membrane molecules through which immunoglobulin molecules signal the activation of inositol phospholipid metabolic pathways. These pathways play a major role in intracellular signaling processes. Still needed is a detailed description of the molecular events that occur as a result of the activation of the signaling pathway.

In parallel with these studies on processes is research on the structures of key molecules in the immune system. This work is yielding details on the structure of the substances involved in the regulation of the immune system, the molecular mechanisms of regulation of the immune response, the complement system, and other critical elements of the immune system, in addition to antibodies and T cells. Ultimately, the results of these profound studies on immunity will lead to practical benefits, including more efficient use of organ transplants by limiting rejection, therapeutic use of molecules such as lymphokines to regulate the immune response, novel approaches to immune therapy and vaccines, and new avenues for treating viral diseases.

Evolution and Ecology

This brief review of modern biology would not be complete without mention of advances in systematics, evolution, and ecology. There is every expectation that research in these areas will, in the next 20 years, have a major influence on medical practice. The field of systematics charts the diversity of life on earth, but this effort is severely challenged in this age of rapid species extinction. Some 1.4 million species of plants, animals, and microorganisms have been described to date, but it is estimated that from several million to perhaps 30 million have yet to be discovered. This is a matter of potentially enormous consequence because civilization is based, to a large extent, on the ability to manipulate the properties of diverse organisms to produce food, shelter, clothing, and many other commodities. A carefully planned effort to identify additional useful species will prove richly rewarding.

The structure and function of communities of ecosystems represent the most complex level of biological integration. Drawing theories and practical methodologies from all other parts of biology, ecology provides feedback by illustrating the adaptive significance of many different characteristics. As the theoretical basis of the field improves, its major concepts are being pressed into service to assist the human race in managing the global ecosystem in a sustainable manner.

Benefits will also flow from an understanding of behavioral ecology. Further studies in this area will improve understanding of such critical areas

as communication, foraging behavior, sexual behavior, kinship, learning, and the roles of the sexes in an ecological and evolutionary context. These theoretical considerations can very well have practical importance. Ecological principles, for example, have been used in the formation of the new discipline of conservation biology. This is being used to understand the biological invasion of pests such as weeds and mosquitoes that transmit infectious diseases.

THE CLINICAL NEUROSCIENCES

Knowledge of the clinical and basic neurosciences is growing at a rapid pace. President Bush and the U.S. Congress officially declared the 1990s to be the Decade of the Brain. It is anticipated that much knowledge directly relevant to military medicine will be gained over the next 20 to 30 years. Twenty years from now there may be a much better understanding of how the brain functions in healthy and diseased individuals, how it develops from conception and changes with age, what it is made up of, and how it interacts with other physiological systems (endocrinology, immunology, etc.). Methods of clinical assessment and treatment of behavioral dysfunction, neuropsychiatric disorders, and neurological disease will be considerably different than they are now.

This new knowledge, if placed in the wrong hands, carries the risk of new threats, such as chemical and biological warfare. It also promises new opportunities to counteract threats from conventional weapons, chemical and biological warfare, disease, battle stress and sustained operations, environmental extremes, and directed energy devices. As more is learned about the neurosciences, the behavioral sciences, and related technologies, new opportunities will emerge to optimize soldier and unit performance, increase disease resistance, treat shock and trauma, repair nerve damage and prevent its progression, increase the physical and psychological readiness of the fighting force, sustain performance, and enhance command and control.

During the past 30 years, cellular neurobiology has become the basis of the clinical neurosciences. Nerve cells are the fundamental signaling and processing units of the brain. They communicate by both chemical and electrical means. Research has identified a variety of specific neurotransmitters and neuromodulators, their receptors, and the mechanisms by which neurons transmit messages from one cell to another, including both extracellular and intracellular actions. This information is fundamental to current understanding of how drugs affect behavior and neuropsychiatric disorders. Recent application of recombinant DNA technology has led to the identification and sequencing of neurotransmitters and receptors, some of which had not been identified. However, despite the significant growth in the number of identified neurotransmitters and receptors, it is still thought that

only a fraction of all neurotransmitters and neuromodulators have been identified. As more knowledge is gained, it is expected that there may be a variety of new pharmacological agents for central nervous system (CNS) functions and disorders. Furthermore, new methods to assess CNS functions, capabilities, and vulnerabilities may be possible.

The following are several areas of the clinical and preclinical neurosciences that have been and will undoubtedly continue to be of particular importance to the Army.

Combat stress. Major causes of lost manpower during combat have traditionally been linked to combat stress, combat fatigue, and shell shock. Furthermore, posttraumatic stress disorder was recently officially recognized in psychiatric nomenclature. Although much has been learned about the recognition and management of these conditions, much remains to be learned about these areas as well as about their etiology, pathophysiology, and prevention. These disorders are likely to be continuing common clinical problems in future conflicts.

Sleep and fatigue. The effects on humans of sustained operations (especially at night) and unusual sleep-wake schedules—loss of sleep, internal and external desynchronization of circadian rhythms, and physical fatigue—are likely to be common problems in the future battlefield, with detrimental consequences for morale, performance, cognitive ability, communication patterns, and judgment. The neurobiological functions and mechanisms of sleep remain poorly understood, although considerable progress has been made and is likely to be made in the future. Likewise, much has been learned about the neural mechanisms of circadian rhythms and their relationships to behavior, performance, and physiological functions as well as about practical methods of shifting or altering these rhythms in an effort to counteract jet lag, shift work, and other disorders.

Effects of chemical and biological warfare. Many of the potential agents of chemical and biological warfare act primarily on the central and peripheral nervous systems—for example, as anticholinesterase inhibitors. Although much is known about the basic neurophysiological mechanisms of these agents, much remains to be learned to detect their effects, diagnose them appropriately, prevent them, and treat them in a military environment.

Trauma to the central and peripheral nervous systems. The proper assessment, management, and consequences of trauma to the nervous system will continue to be major problems in future combat. Exciting new knowledge of the mechanisms of neuronal injury and death associated with trauma, stroke, and ischemia promise advances in the treatment of trauma to the brain and spinal cord. Furthermore, new imaging techniques, surgical concepts, and medications (e.g., anticonvulsants) offer additional hope.

Analgesia. With the discovery of endogenous analgesic substances (i.e., the enkephalins and endorphines) and their receptor systems, renewed interest has been focused on the neurobiological mechanisms of pain. Continued

research and development (R&D) may provide new methods of treating these clinical syndromes.

CNS-active infective agents. The indirect effects of systemic infections on the CNS and the risks of direct CNS infection from either endemic diseases or biological warfare agents remain major concerns of the Army. Most recently, the effects of human immunodeficiency virus infections have received considerable attention. The interrelations between the brain and the immune system have been increasingly recognized in recent years and offer new approaches to understanding and treating such conditions.

Drugs and alcoholism. Misuse of drugs and alcohol is a major cause of lost manpower and poor performance among military personnel, as well as a high-priority concern to civilian leaders. The Army must continue to deal with substance abuse among military personnel and be on the front lines of the nation's war on drugs. The neurobiology of substance abuse as well as the factors that predispose an individual to, precipitate, and perpetuate substance abuse remain poorly understood. It is likely that much will be learned at the neuroscience and clinical levels that will lead to new methods to detect, interdict, diagnose, and treat substance abuse.

Effects of directed energy devices on the CNS. A new generation of weapons that use microwaves, lasers, and other forms of directed energy is emerging. Their effects are understood with varying degrees of certainty—for example, from their well-documented devastating effects on the eye to their poorly documented effects (if any) on behavior. Although there has been public concern about the possible adverse health effects of nonionizing radiation, little research has actually been done outside a military setting.

Projected Status and Applications

Many developments and applications are anticipated in the neurosciences in the next 20 years. Among them is *new knowledge about neural development*. Such knowledge includes neural induction, neural proliferation, migration, cell aggregation, cytodifferentiation, axonal outgrowth, and neuronal death. The potential applications of this knowledge include management of trauma to the central and peripheral nervous systems and the musculoskeletal system, prevention of age-related deterioration, and surgical and neural transplantation technologies.

New knowledge about the chemical constituents of the nervous system will evolve. There is new knowledge yielding data regarding precise anatomical localization; functions and interrelationships with other systems; and mechanisms that control the synthesis, levels, degradation, and transport of chemical constituents of the nervous system. It is possible that new pharmacological, nutritional, and experimental methods of assessing and influencing brain function and behavior will develop from this knowledge.

In the next two decades, *understanding of the neurobiological basis of fundamental behaviors* will increase. These behaviors include the study of movement, attention, perception, cognition, motivation, learning, understanding and use of language, and emotion. Potential applications may include biotechnological methods of human-machine interactions; biological models of development of hardware and software technology; and pharmacological approaches to prevention, treatment, and performance enhancement.

Brain imaging methods to assess structure and function will be improved. Computerized axial tomography and magnetic resonance imaging are now available for assessing brain structure. Positron emission tomography, cerebral blood flow detection methods (i.e., 133-labeled xenon), single-photon emission computerized tomography, brainstem and cortical averaged evoked potential, cortical electroencephalographic mapping, magnetic resonance spectroscopy, and magnetoencephalography are currently used to assess brain functioning. Potential developments will aid in the diagnosis, assessment, and prediction of function and behavior. Brain-imaging methods can be used for diagnosis and research on neurological, psychiatric, and substance abuse disorders; for assessment of specific neurotransmitter or receptor activity within a narrow resolution of time and neuroanatomical space; and for assessment of drug action and function.

A better integration between brain, neuroendocrine, and neuroimmune function will be developed. This integration includes, for example, the reciprocal interactions between immunological cytokines (i.e., interleukins), neuroendocrine factors (e.g., corticotropin-releasing factor), and CNS function. Developments in this area have the potential of increasing our ability to enhance CNS, neuroendocrine, and neuroimmune function and of better management of CNS infections.

The creation of *new neuropsychopharmacological agents* will occur within this time period as well. Such agents are capable of affecting specific functions or disorders: learning, memory, attention, motivation, reward systems, anxiety, sleep, analgesia, psychic and physical energy, mood, specific psychiatric and substance abuse disorders, neural excitability, and cell death. Potential applications include enhanced and sustained performance; treatment of stress and fatigue or specific disorders; new analgesic agents that could be used in the military environment without the risk of addiction, respiratory impairment, or impairment of judgment or performance; development of anxiolytic and hypnotic agents that do not adversely affect motor function or judgment; and prevention of progressive neural injury, for example, by blocking adverse effects of excitatory amino acids.

New methods for assessing genetic factors will evolve. Such methods and their specific molecular mechanisms in human behavior, temperament, and neuropsychiatric disease could be applied for prediction of individual capabilities and vulnerabilities; for understanding the relationships between

nature and nurture; for prevention, diagnosis, and treatment; and for matching an individual to specific tasks.

Within this time period, *a more sophisticated interrelationship between neurobiology, neural models, computer software, and engineering will unfold.* This interrelationship has the potential for neural networks, systems theory applications, and detection and control systems in bioengineering applications.

Advances in clinical pharmacology are evolving. These advances include accurate quantitative detection of pharmacological substances and their metabolites in body tissues and at specific sites of action as well as a better understanding of pharmacokinetics and pharmacodynamics. They have the potential for easy and accurate monitoring of drug levels in individual patients in the military environment with appropriate clinical calculation of dose and dosing schedules. Other possible uses include assessment of benefits and side effects, for example, for pilots or infantrymen taking anxiolytic or hypnotic agents; use of brain-imaging methods to determine appropriate levels of CNS active medications at specific brain sites; and diagnosis of substance abuse.

Finally, *identification of human pheromones* may be possible within the next 20 years. Potential applications include new means of identifying and detecting individuals and the ability to modulate sexual behavior or endocrine function.

Impacts on the Army of 2020

The Army must be as innovative in its development of high technologies for the prevention and treatment of trauma and disease as it has been in the development of new weapons. In the next 25 years it is possible that biotechnological and clinical progress could be made to the advantage of military missions in the following areas.

Selection of personnel for military duty. Individuals at high risk for disease susceptibility (for such ailments as psychiatric disorders, substance abuse, immunodeficiency, or an inability to tolerate stress) could be identified.

Training (cognitive and physical). As military equipment and skills become increasingly sophisticated, it will be necessary to train personnel to high levels of skill and motivation. It may be possible to either select individuals more effectively for specific tasks or to use specific medications (memory enhancers) or better teaching strategies to enhance memory, motivation, attention, the rate and effectiveness of learning, or performance. Physical training, fitness, and endurance could be enhanced by the development of safe anabolic steroids, alertness enhancers (safe stimulants for use during the day, safe sleeping pills for use at night), or new methods for assessing or tailoring physical training (i.e., physical kinetics).

Threat assessment. Psychological threats and propaganda have always been important in both offensive and defensive military postures. Chemical

and biological weapons will also continue to be potential risks in future conflicts. Military units and personnel must be prepared to recognize all of these threats, assess them appropriately, and defend against them. Biological or chemical detection systems—for example, polymerase chain reactions (novel systems for gene amplification), pheromones, or similar substances—might be used for such purposes.

Prevention and maintenance. A host of new technologies that may prevent diseases are now available. There are ways, based on new molecular biological techniques, to produce vaccines. Infection may be prevented by drugs that enhance immunity. And stamina at high altitudes may be enhanced by blood expanders. Sleep deprivation, fatigue, and stress reactions could be prevented by safe medications. For example, sleeping pills without effects on memory or performance and stimulants without risk of addiction are needed during high-intensity and low-intensity conflict, during training, and to counteract jet lag. The basic mechanisms and functions of sleep and chronobiology remain largely unknown. Still mysteries are (1) the physiological mechanisms that underlie sleepiness after sleep deprivation or as a function of circadian rhythm, (2) how sleep reverses the effects of sleep deprivation on performance and subjective dysphoria, and (3) what functions sleep has for normal brain and body function (i.e., rest or restoration). The role of individual differences in timing and duration of sleep also remains, for the most part, unknown. More research on the fundamental functions and mechanisms of sleep and chronobiology, as well as the development of safe and effective countermeasures, is needed. For example, new pharmacological agents might be developed in the next 25 years. A better understanding of optimal sleep-wake schedules and light-dark schedules may be developed to maximize individual performance; tolerance of sleep loss; and to allow for adjustments to shift work, rotating and irregular schedules, and jet lag. New and safe anxiolytic agents, analgesics, stimulants, or mood elevators may also become available to help military personnel cope with stress without affecting performance. Stress management programs, both those that are preventive and those that help alleviate stress after it occurs, should be considered to prepare personnel for combat and to avoid post-traumatic stress disorder.

Casualty assessment. Medics and unit commanders both need methods for rapid, easy, and accurate assessment of individual military personnel who may become casualties because of trauma, infection, or neuropsychiatric disorders. One such method would be a telemetry device given to each soldier to monitor all vital functions. This could provide a commander with an immediate evaluation of fighting capability and a field medic with information about the status of casualties. Immediate detection and evaluation of battle casualties could allow early treatment, which could result in a 10 percent reduction in mortality. Other methods might include well-validated, reliable, structured interviews as well as technological innovations such as ambulatory recording devices that assess longitudinal sleep-wake and ambulatory

light-dark profiles (i.e., every minute for days to weeks), performance batteries (i.e., reaction time and continuous performance), enhancements to improve cognitive and memory skills, and average evoked potentials (e.g., ambulatory P300 measures or new physiological methods of measuring sleepiness). New oxygen-carrying fluids, as well as robotic evacuation vehicles and computer satellite monitoring of shock status, will reduce battlefield deaths by more than two-thirds.

Triage. Rapid and accurate clinical assessment is needed for personnel who have been identified as combat stress or neuropsychiatric casualties and for whom a treatment decision should be made (i.e., short-term treatment with the expectation of rapid return to duty or longer-term treatment). One approach might be the development of biological markers or measures that could assist in the differential diagnosis of acute stress reaction versus malingering, acute mania, schizophrenia, or toxic psychosis. Another major problem faced in triage is the treatment of hemorrhagic shock. For this, blood substitutes and new treatments for shock mediators are needed.

Treatment. Advances in treatment will result in rapid and more effective restoration of health. There are many areas in which major advances can be expected. Growth factors that will regenerate nerves, enhance wound healing, and restore radiation-induced bone marrow damage will be used. Skin and other tissue transplants will become as routine as blood transfusions. The high mortality rate from septic shock will be prevented by new drugs. New insight into the interface of blood and blood vessels will permit less tissue damage and greater salvage of damaged organs. And new pharmacological treatment to eliminate long-lasting combat stress will be developed.

ENABLING TECHNOLOGIES

Modeling and Assessment Technologies

The military services have a long tradition of using wargames, computer models, and battlefield simulations to evaluate the capabilities of new equipment, tactics, and organizations for combat. These modeling and assessment tools address a range of units (e.g., crew, company, division, and theater), geographic scenarios (e.g., Central Europe, Southwestern Asia, Latin America), and missions (e.g., combat units, fire support, command and control, and logistics). A conspicuous absence from these models is an in-depth consideration of human capabilities and limitations. The evaluation of soldier enhancement technologies is virtually nonexistent in combat models. Yet central to the exploitation of any new materiel technology is the ability of the soldier to interface with and effectively operate systems under the threats and stresses of combat operations.

During the past several years, the military-operations research community has become interested in the problem of these so-called *soft factors* in standard Army models. At the same time, the U.S. Army Medical Research and Development Command has been striving to model the impact of its medical products on the battlefield. Together, these two initiatives could have a widespread impact on the incorporation of soldier-oriented concepts into overall Army R&D. These impacts will be felt in three areas:

1. *Evaluation of potential soldier-oriented R&D.* Modeling and analysis will permit the Army's leadership to evaluate the future benefits of soldier-oriented research with the same tools and weapons and, accordingly, the same terms of reference that will be used to evaluate weapons systems performance. This new understanding of the role of soldier capabilities and the impact of products to sustain the soldier on the battlefield, including medical protective and therapeutic interventions, will provide the Army's leadership with a more rational approach to allocating resources to this category of R&D in proportion to its impact on future war-fighting potential.

2. *Prioritization of soldier-oriented R&D.* There are many approaches to providing support for the soldier facing a variety of threats on the battlefield. Each has its virtues and its negative aspects. Combat models can serve as a decision aid for selecting among competing R&D alternatives. For example, defending the soldier against biological threat agents can be accomplished with either vaccines before exposure or with postexposure prophylactic therapies. Vaccines are expensive to develop, are usually specific to a single agent, and require accurate intelligence regarding threat assessment. Postexposure therapies may be effective against a variety of threat agents (a class of viruses) and can be administered after the threat is detected and identified, but they are most effective when administered in advance of symptoms. Combat modeling has provided the medical R&D command with specific guidance as to the relative benefits of these two approaches and specific guidance on ways to decide between them.

3. *Identification of new avenues of research.* Modeling of specific threats and potential interventions can identify gaps in knowledge about the disease process and can design criteria for potential interventions. These results can guide the direction of future research and selection of specific candidate therapies. For example, therapies to protect against chemical agents may differ in their therapeutic properties: one therapy may protect against higher doses but have a limited duration of action; another may be less potent but persist longer in the system. Computer modeling of the threat can indicate the likely exposure levels and their persistence on the battlefield, permitting a rational selection among the intervention alternatives.

In addition to these modeling and analysis tools, the Army must have a robust methodology for measuring soldier capabilities under a variety of

battlefield conditions. This methodology must include a battery of objective assessment tests, a taxonomy of military tasks and their relationship to these test results, and a data base of test results from human and nonhuman experiments. The information can then serve as an accurate input parameter for the modeling and analysis process. Together, modeling and assessment are enabling technologies that will serve to focus attention on individual soldier research, both medical and nonmedical, and on those concepts with the greatest net benefit for sustaining the soldier and accomplishing the combat mission.

Electric Power Generation and Storage

The tools for energy generation, storage, and conversion for powering field devices ranging from individual soldier communicators to far-forward medical treatment stations must become more compact, weigh less, and have a high-power capacity and extended life. At the same time, they should be able to tolerate environmental extremes of temperature and altitude, mechanical shock, etc. Battery, fuel cell, and other energy storage technologies are relevant to the power requirements in far-forward positions in the battlefield, whereas continuous power generators are appropriate for electrical power requirements at rear-echelon hospitals.

Batteries may become an increasingly important source of energy for rapidly mobile medical units deployed to forward positions. Considerable work is in progress to improve the rechargeable nickel-cadmium battery for use as an external and internal power source for medical devices. Among the most promising types of battery is one with lithium/transition metal chalcogenide cells. The development of a new ternary electrolyte has vastly improved the performance of the earliest batteries. Compared with the nickel-cadmium batteries, the new rhenium-lithium cells have equal performance with half the weight and volume and twice the safety margin. The skills and technical capability exist to continue this improvement in battery design for larger batteries that will deliver a higher energy output. These technologies are discussed in depth in the propulsion and power section of the STAR Technology Forecast Assessments volume (NRC, 1993a).

Mobility and Robotics

Future casualty retrieval and mobile forward-echelon medical facilities (both discussed in Chapter 3) will be based on enabling technologies directed toward enhanced vehicle mobility on the battlefield. Research on tracked, trackless, and legged mobile platforms will be relevant, as will related progress in energy sources, sensor technologies, propulsion systems, and

systems integration. Future platforms will be augmented by a robotic capability that will lift, move, and orient casualties onto the platform and will use miniaturized equipment and emerging technologies to ensure adequate medical attention (e.g., cardiopulmonary resuscitation during the retrieval process).

TECHNOLOGY, SYSTEM INTEGRATION, AND THE SOLDIER

Throughout the discussion in Chapter 3 of soldier support systems on the battlefield, soldier-borne communication, navigation, sensor, and computer systems were mentioned frequently. These systems may very well evolve independently of any medical considerations; however, many additional benefits will be made possible by incorporating biosensors and medical communications to support the soldier's physical and psychological capabilities. Systems for the prevention of dehydration, heat prostration, fatigue, battle stress, and acute disease must become integral parts of the soldier system in order to minimize duplication of hardware and software assets and to incorporate information from sensors and the communications network. Artificial intelligence will provide processed information based on sensor data and internal-decision algorithms to guide the soldier.

Soldiers must not become casualties of technology, overburdened by the addition of layer upon layer of specialized and uncoordinated separate *capability enhancements* that duplicate functions and compete for electric power, load capacity, soldier attention, and communication bandwidth (see the Special Technologies and Systems Panel report for conclusions and recommendations regarding the soldier as a system (NRC, 1993b)). Such will be the case if each command develops a plan to coordinate and implement equipment designs and contributions but fails to coordinate the information and developments with other commands. Soldiers can also be the victims of high-technology weapons systems that pay insufficient attention to the human operator's needs and limitations, both physical and psychological. This is likely the result of the current development process, which includes few proponents of the individual soldier. The ultimate result may well be a poorly managed individual soldier who will suffer, at best, avoidable capability limitations and, at worst, increased medical incapacitation.

At another level, the design decisions on all hardware systems that include a human operator must incorporate some consideration of human capabilities, limitations, and vulnerabilities. Future high-technology equipment must be comfortable and safe to operate, must support and even anticipate the psychological requirements of the soldier, and must be protected from environmental and hostile hazards. Weapon systems should not only consider the soldier but also serve to enhance his or her capabilities so that the capabilities of the entire system are greater than the sum of its parts.

The need for integration of the soldier system and of the soldier into other systems may require the creation of an Army-wide soldier integration steering committee with representatives from all of the Army's development agencies. This committee would serve to coordinate parallel R&D activities as well as the insertion of product modules into the overall design system. It would set standards for hardware and software architecture and interfaces to ease this integration. It would also define systems requirements for power, radio communications frequencies and protocols, data storage, and sensor design criteria. In some cases the committee might assign the lead responsibilities for R&D to commands or competing agencies. An overall steering committee would offer the benefits of integration while preserving the unique capabilities inherent in each development agency for medical, combat materiel, and personnel support.

CONCLUSIONS AND RECOMMENDATIONS

To ensure the performance enhancement, sustainability, and survivability of the individual soldier, the Army must continue to monitor all future prospects and advances in science and technology. The panel suggests that establishing a soldier integration steering committee to coordinate parallel R&D efforts and insert modules into the system design might prove advantageous. It strongly advises that the Army maintain the technology edge and exploit relevant technologies by:

Investing in and developing resources capable of identifying and adapting emerging technologies to the medical needs of the Army, especially the individual soldier. This may be achieved by stressing more effective use of computing systems and high-speed data-processing techniques for medical data management, modeling, and display technology, all of which will aid and enhance research and analysis.

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Appendix A

Demographic and Manpower Trends: Implications for the Army of the Future

The soldiers of tomorrow are now children and adolescents. Their current mental and physical health, education, cognitive abilities, personal and interpersonal skills, patriotism, and motivation are critical in preparing for the country's future. Traditionally, nearly one-third to one-half of the potential military manpower pool has been rejected as medically or psychologically unsuitable before they are accepted for active duty and another one-fifth are released early in training for similar reasons. The capabilities of many active-duty soldiers are limited by physical and psychological disabilities or educational deficiencies. These numbers represent a major loss of military manpower--one greater than that caused by enemy bombs and bullets.

The prevention and treatment of medical and psychological disorders among U.S. children must be general goals of society at large. Such measures could make for happier, healthier, and more productive adults. In the context of the present report, these preventive and remedial measures are necessary to increase the potential pool of soldiers in a citizens' army and would enhance the ability of the country to survive future military, economic, and other threats.

As the military prepares for the future, current demographic trends have important long-term implications for the military manpower pool and for the psychological and medical issues that the Army must address. *Opportunity 2000*¹, a 1988 publication of the U.S. Department of Labor, predicts major trends that will revolutionize the general work force in the United States in the next decade. Some of these trends will have a great impact on the personnel composition of the Army of the future.

The total number of civilian workers will fall. The number of young workers (age 16 to 24) entering the work force will fall by almost 2 million between now and the year 2000. While the labor force grew by 53 percent between 1960 and 1980, it is expected to increase by 32 percent between 1980 and 2000. Therefore, the Army will probably have to draw on a smaller manpower pool than it has in recent decades. Unless this trend is reversed, the Army, and especially the medical command, may face difficulties satisfying

¹U.S. Department of Labor. 1988. *Opportunity 2000: Creative Affirmative Action Strategies For a Changing Workplace*. Washington, D.C.: U.S. Printing Office.

the demand for medical and psychological researchers and caregivers. Physical and psychological entrance standards for military personnel may have to be lowered if large numbers of soldiers are needed. Remedial treatments may be necessary to prepare some recruits for military training because of preexisting medical, dental, and psychological conditions.

Education will be important, not only to correct the basic academic deficiencies of many youth who are poorly prepared scholastically but also to enable all soldiers to effectively use the high technologies on which the Army will depend. New technologies from the psychological sciences, cognitive sciences, and neurosciences may offer faster and more effective ways to teach and train soldiers.

New methods of physical training and conditioning may enable soldiers to attain higher levels of physical performance. These methods could be especially useful for physically unfit and unprepared individuals, many of whom may have had a disadvantaged childhood or may be older than current recruits.

Considerable progress has been made in recent years in preventive and sports medicine. At the level of competitive sports, this has resulted in new world records. At a societal level, interest in physical fitness, nutrition, and a healthy life-style have increased and have been partially credited for the falling rates in cardiovascular disease. Techniques of physical training are advancing on the basis of physiological and biomechanical principles (i.e., kinesthesia). Methods to prevent and correct certain types of injuries (e.g., knee injuries) have improved and will continue to improve with the advancement of new technologies (e.g., arthroscopy). And although pharmacological enhancers of physical performance (e.g., anabolic steroids and stimulants) have rightly been condemned, it is likely that new pharmacological agents will be developed that will be relatively safe and that increase an individual's physical strength, endurance, recovery, and performance. All of these emerging technologies may prolong physical and mental health. They, along with other advances beneficial to the individual, will help the Army to create a qualified force despite a decreasing manpower pool.

The average age of the work force will rise. Between now and the year 2000, the number of workers between the ages of 35 and 54 will increase by 25 million. The median age of employed Americans will go from 36 in 1987 to 39 in the year 2000. Although the Army has traditionally emphasized the physical strength, speed, and stamina of youth, the number of physically fit young males will decrease during the next quarter of a century. Because manpower pools may be limited, it may be advantageous, in time, to treat and subsequently enlist some individuals currently excluded for medical or psychological reasons. For example, new treatments may enable individuals who have had diabetes, hypertension, cystic fibrosis, or sickle cell anemia or who have suffered from substance abuse to serve in the Army.

If the average age of the soldier increases over the next quarter of a century, preventive medicine may be more important to enable the soldier to perform well over a career of 20 years or more in the military. New knowledge about the physiological mechanisms of aging may emerge, which could extend the effectiveness of the American soldier.

More women than ever will be in the work force. Only 15 percent of the net additions to the work force will be white males. The majority of new entrants will be women and minorities. By the year 2000, 47 percent of the work force will be women and 61 percent of all women will be employed. Moreover, it is anticipated that increasing numbers of women will enter professions that have traditionally been considered "male," such as computer science, engineering, management, medicine, and law. The Army should expect that increasing numbers of women will be interested in military careers, especially if the doors previously closed to them regarding participation in active combat service swing open. Many of these women will have the specific technical skills the Army needs; furthermore, sufficient number of men will not be available to fill the Army's needs.

The Army will have to recognize and manage the medical and psychological needs of women in the service. For example, military physical fitness standards have traditionally been considered too rigid for many women. Biomedical technologies for enhancing physical strength, as well as the increased participation of women in competitive sports and physical fitness programs, will permit increasing opportunities for women.

Most new jobs in the work force will be in services and information. The new jobs will be ones that require higher skills. For example, new jobs for scientists--whether natural, computer, or mathematical--will increase by 68 percent; jobs for technicians will increase by 44 percent; and jobs for health diagnosis and treatment specialists will increase by 53 percent. Nearly one-third of all new jobs will require a college education, while the number of unskilled jobs will fall. A technologically sophisticated military will increasingly need skilled personnel but may be at a disadvantage in recruitment compared with civilian employers because of pay and life-style.

These demographic trends suggest that the future military recruitment pool will be smaller and older than in recent years and that it will have a greater proportion of women, minorities, and foreign-born individuals. At the same time, however, there is disturbing evidence that a growing proportion of American youth are not being prepared for the demands and opportunities of the future. Too many children are living in poverty, without adequate health care, education, hope, or good role models. Because of their poor medical and psychological health, academic and interpersonal skills, motivation, and work habits, by the time today's children enter the twenty-first century, many of them will never be able to succeed in either civilian or military adult roles. Unless these trends are reversed, the Army and, especially, the medical

command may in the future face difficulties—with important implications for medical and psychological care and research.

Appendix B

Biographical Sketches of Panel Members

Richard M. Krause (*Chairman*) has been senior scientific advisor at the National Institutes of Health (NIH) since 1989 and is a physician, immunologist, and microbiologist. He has been actively involved in basic research on the substances in bacteria that trigger the protective mechanisms of the body's immune system. Dr. Krause graduated from Marietta College and Case Western Reserve University School of Medicine. Following faculty appointments at Washington University School of Medicine and the Rockefeller University, he assumed the position of director of the National Institute of Allergy and Infectious Diseases at NIH in Bethesda, Maryland, in 1975. In 1984 he was named Woodruff Professor of Medicine and dean of the School of Medicine at Emory University. Dr. Krause is a member of several distinguished societies and organizations and has received several scientific awards and honors. He had authored numerous publications, including a collection of essays entitled *The Restless Tide*, which tells the story of microbes invading the human body and the immune system's response to them.

William R. Drucker (*Vice-Chairman*) is a professor in the Department of Surgery of the Uniformed Services University of the Health Sciences in Bethesda, Maryland. He received his M.D. from the Johns Hopkins University School of Medicine and his B.S. from Harvard College. He served in the U.S. Navy at the Naval Medical Research Institute, Bethesda, Maryland, and at Naval Medical Research Unit #3, Cairo, Egypt. From 1954 to 1966, Dr. Drucker taught surgery at Case Western Reserve University School of Medicine and became professor of surgery. He was professor and chairman of the Department of Surgery and surgeon-in-chief at Toronto General Hospital until 1972, when he became professor of surgery and dean of the School of Medicine at the University of Virginia, and chief of staff at the university's hospital. In 1977 he was named professor and chairman of the Department of Surgery and surgeon-in-chief at Strong Memorial Hospital, Rochester, New York. Dr. Drucker is a member of several American and Canadian medical associations and societies. He is also the author or coauthor of several technical papers and articles and is on the editorial board of the *American Journal of Surgery*.

Joseph M. Davie has been president of research and development at G. D. Searle & Co. since 1972. He has worldwide responsibility for Searle's R&D activities, including the operations of major research centers throughout midwestern United States and in Europe. Prior to working at Searle, he was professor of microbiology and immunology at Washington University School

of Medicine. He also held positions at the National Institutes of Health in pathology and immunology. Dr. Davie received his B.A., M.A., and Ph.D. degrees in bacteriology from Indiana University and his M.D. in 1968 from Washington University School of Medicine. He has authored more than 175 publications and is recognized worldwide as an authority on bacteriology and immunology. Dr. Davie was elected to membership in the Institute of Medicine of the National Academy of Sciences in 1987.

J. Christian Gillin is professor of psychiatry at the University of California, San Diego, and staff psychiatrist at the San Diego Veterans Administration Medical Center. He earned a B.A. magna cum laude from Harvard College and received his M.D. from Case Western Reserve University School of Medicine. Dr. Gillin served with the U.S. Public Health Service for 14 years and in various capacities at the National Institute of Mental Health, where he achieved a final rank of medical director. He is presently a captain in the U.S. Naval Reserve and, in addition to his other positions, is director of the Mental Health Clinical Research Center at the University of California, San Diego (USCD); he also received a USCD fellowship in clinical psychopharmacology and psychobiology. His specialties include affective and sleep disorders, and he has conducted research in the field of psychopharmacology. Dr. Gillin is editor-in-chief of *Neuropsychopharmacology*. He is a member of many associations and is a fellow of the American Psychiatric Association. Dr. Gillin has coauthored a book, *Human Sleep and Its Disorders*; about 300 articles; and several book chapters.

Robert W. Mann is Whitaker Professor of Biomedical Engineering at the Massachusetts Institute of Technology. Dr. Mann began his education at MIT and received his Sc.D. in 1957. He has served the Institute in many capacities over the past 49 years. He has been a research engineer, assistant professor, associate professor, professor of mechanical engineering, germeshausen professor, and professor of engineering. Dr. Mann also served in the U.S. Army Signal Corps during World War II. He is a respected expert in the fields of rehabilitation, prosthetics, and orthopedic research. His work concentrates on the melding of engineering, biology, and medicine. Dr. Mann has served on several national committees on engineering design, health science design, prosthetics research and development, computer-aided design technology, rehabilitation of the physically handicapped, and other topics. He holds concurrent memberships in the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine and has received many awards and recognitions, including Massachusetts Professor of the Year in 1985. Dr. Mann holds four patents and is author or coauthor of over 250 publications.

Jay P. Sanford is currently president of Antimicrobial Therapy, Inc. and dean emeritus and professor of military medicine at the F. Edward Hebert School of Medicine. He was president and dean of the School of Medicine, Uniformed Services University of the Health Sciences, Bethesda, Maryland, from 1975 to 1990 and was a consultant in infectious diseases at Walter Reed Army Medical Center (WRAIR) and the National Naval Medical Center, Washington, D.C. Previous positions include professor of internal medicine, University of Texas Southwestern Medical School, Dallas, and chief of the infectious diseases services and director of microbiology laboratory, Parkland Memorial Hospital, Dallas. Dr. Sanford was also director of disaster medical care, Texas Region 1A. He graduated cum laude from the University of Michigan Medical School and received his graduate training in internal medicine at the Peter Bent Brigham Hospital, Harvard Medical School, and Duke University Medical Center. He served as a captain (MC) in the U.S. Army Reserves at the WRAIR and is currently a colonel (MC) USAR assigned to the 11th Special Forces Group (Abn). Dr. Sanford has served on numerous committees, is a member of the Institute of Medicine, of the National Academy of Sciences, the American Society for Clinical Investigation, the Infectious Diseases Society of America, and the Association of Military Surgeons of the United States. He has also been a member of many editorial boards and has received numerous honors. Dr. Sanford has published extensively in the area of infectious diseases, including original research, textbook chapters, and reviews and is author or coauthor of over 300 publications.

Kenneth W. Sell is professor and chairman of the Department of Pathology and Laboratory Medicine, Emory University School of Medicine and is also director of the Winship Cancer Center, coordinator of the Emory Transplantation Programs, and professor of the Department of Pediatrics. He received his M.D. from Harvard University and his Ph.D. in immunopathology from the University of Cambridge. He has held teaching appointments at Emory University School of Medicine; Georgetown University Medical School; the Foundation for Advanced Education in the Sciences, Inc.; the Uniformed Services University of the Health Sciences; and Walter Reed Army Medical Center. He served in the U.S. Navy Medical Corps for 21 years and was commanding officer of the Naval Medical Research Institute from 1974 to 1977. Dr. Sell is a noted expert in immunology and pathology. He is a member of over 32 academic and professional societies and has received many awards. He has authored or coauthored many papers and has written five books and symposia proceedings.